AAMRL-TR-85-044

NIGHT VISION GOGGLE HEAD-UP DISPLAY FOR FIXED-WING AND ROTARY-WING SPECIAL OPERATIONS

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JUNE 1985

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NOTICES

TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-85-044

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
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Harry G. Armstrong Aerospace Medical Research Laboratory

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION	Unclassified
1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
3. DISTRIBUTION/AVAILABILITY OF REPORT	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	AAMRL-TR-85-044
5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION	Systems Research Laboratories, Inc.
6b. OFFICE SYMBOL (If applicable)	
7a. NAME OF MONITORING ORGANIZATION	AAMRL/HE
6c. ADDRESS (City, State and ZIP Code)	2800 Indian Ripple Road Dayton, Ohio 45440
7b. ADDRESS (City, State and ZIP Code)	AMD, AFSC Wright-Patterson AFB, OH 45433
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	
8b. OFFICE SYMBOL (If applicable)	HED
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	F33615-82-C-0511
8c. ADDRESS (City, State and ZIP Code)	
11. TITLE (Include Security Classification)	See reverse side.
12. PERSONAL AUTHOR(S)	See reverse side.
13a. TYPE OF REPORT	Draft
13b. TIME COVERED	FROM ______ TO ______
14. DATE OF REPORT (Yr., Mo., Day)	June 1985
15. PAGE COUNT	155
16. SUPPLEMENTARY NOTATION	

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62202F	7184	12	15

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Night Operations; Covert; Night Vision Goggles; Head-Up Displays

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the development and evaluation of night vision goggles (NVGs) modified with head-up display (HUD) symbols for flying night, visual flight rule (VFR), low level operations. The NVG/HUD combines NVG compatible symbols on a monocular presentation with a binocular view of an infrared scene. The Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) sponsored the development program for special Military Airlift Command (MAC) operations using fixed- and rotary-wing aircraft.

NVG/HUDs were used by 30 pilots flying eight models of jet and turboprop cargo aircraft and conventional helicopters in night sorties. Questionnaires and interviews were used to guide design changes, suggest training requirements, and assess pilot acceptance. No system performance data were recorded; however, the pilots rated the adequacy of each display symbol (e.g., airspeed, altitude) and its implementation (e.g., size, location, movement) for flying low level operations.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☒ DTIC USERS ☐
21. ABSTRACT SECURITY CLASSIFICATION	Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	Jeffrey L. Craig
22b. TELEPHONE NUMBER (Include Area Code)	(513) 255-7592
22c. OFFICE SYMBOL	AAMRL/HED

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

SECURITY CLASSIFICATION OF THIS PAGE

3. (continued)

Distribution is limited to U.S. Government Agencies; test and evaluation (November 1983). Other requests for this document must be referred to AAMRL/HED.

11. (continued)

NIGHT VISION GOGGLE HEAD-UP DISPLAY FOR
FIXED-WING AND ROTARY-WING SPECIAL OPERATIONS

12. (continued)

Simons, John C., Unger, Sheldon, Craig, Jeffrey L.*

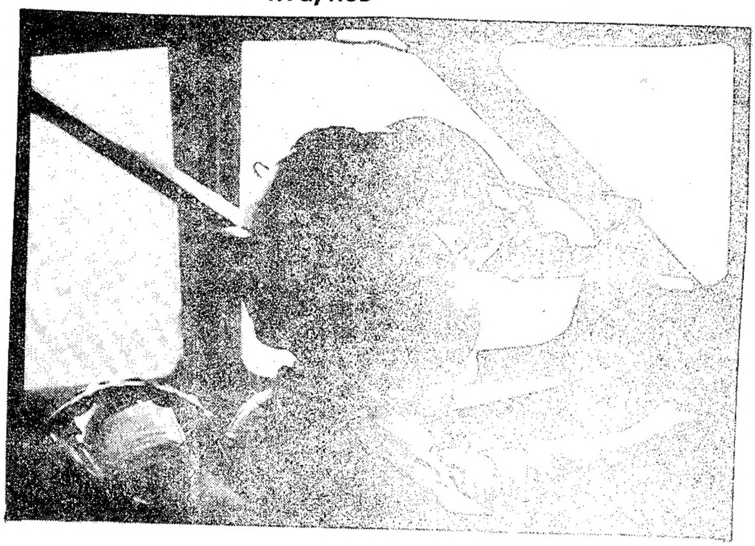
16. (continued)

*Harry G. Armstrong Aerospace Medical Research Laboratory

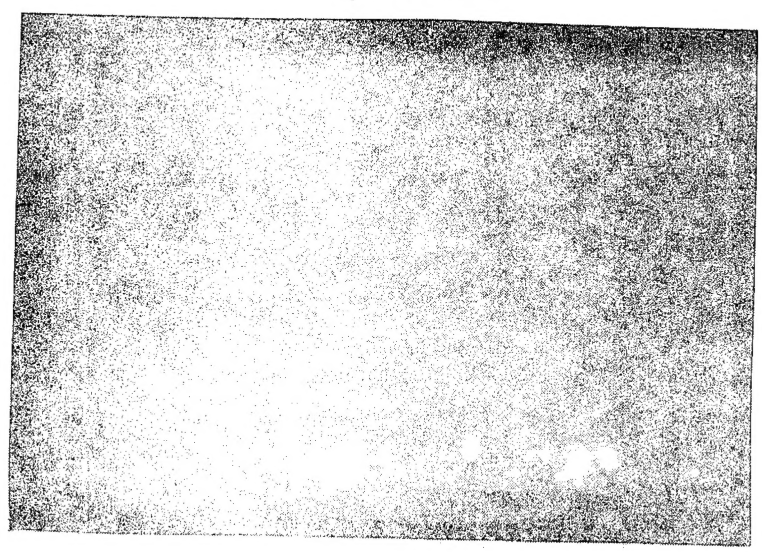
19. (continued)

The system was rated as an absolute requirement by the majority of pilots for most of the missions with minor changes in symbol selection and characteristics. They recommended the 14-degree Instant Field-of-View (IFOV) be expanded within 40-degree IFOV of the NVG goggle and an increase in size for many symbols. Recommendations for cockpit controls, training, and future studies are also reported.

NVG/HUD



NVG/HUD Scene



PREFACE

This report describes the development, evaluation, and application of night vision goggles (NVG) modified with head-up display (HUD) symbols. The NVG/HUD system was designed for flying night, visual flight rule (VFR), low level operations. The results proved to be generalizable to a variety of aircraft and missions. The report was prepared in part by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton, Ohio 45440, under Contract F33615-82-C-0511. The work was performed in support of the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL), Project 7184-12-15, Lighting and Light Control, under the direction of Mr. Jeffrey L. Craig for the Human Engineering Division (HE), Wright-Patterson Air Force Base, Ohio 45433.

The authors gratefully acknowledge the contributions of Dr. Harry Lee Task who designed and developed the NVG/HUD display, the assistance of Mr. David Lambertson who designed and reported the aircraft instrumentation interfaces, and to Ms. Carla Reese (SRL) who tabulated the pilot questionnaire responses.

Special acknowledgements are made to the following MAC personnel who coordinated the field and flight test trials:

Capt. Doyle Walker, Airlift Center, Pope Air Force Base, NC
Maj. Terry Silvester, SMOTEC, Hurlburt Field, FL
Maj. Richard Runyon, SMOTEC, Hurlburt Field, FL

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Section 1
INTRODUCTION

This report documents the development, evaluation, and application of night vision goggles (NVGs) modified with head-up display (HUD) symbols for flying night, visual flight rule (VFR), low level operations. The NVG/HUD combines NVG compatible symbols, infinitely collimated for a monocular presentation, and a binocular view of an infrared scene. The Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) conducted the evaluation program for special Military Airlift Command (MAC) operations.

The NVG/HUD was used by 30 pilots flying eight models of jet and turboprop cargo aircraft and conventional helicopters in night sorties. Questionnaires and interviews were used to guide design changes, suggest training requirements, and assess pilot acceptance of the NVG/HUD device.

This section includes a brief description of requirements for development of the NVG and NVG/HUD for night, low level operations. The approach for qualifying the NVG/HUD in successive aircraft is described, a background discussion of NVG state of the art is presented, and a list of test objectives is included. Section 2 includes the critical mission factors for all of the aircraft. (Unless noted otherwise, the term "aircraft" includes fixed-wing and rotary-wing aircraft.) Descriptions of NVG/HUD equipment, crew experience, and the development of the evaluation questionnaires are also highlighted. Section 3 summarizes the results of the in-flight tests. Section 4 presents the final display/control configurations, suggested training requirements, and recommendations for NVG/HUD applications.

Appendices include descriptions of the NVG/HUD demonstration device used in this study and the questionnaires and their responses used to evaluate the device.

BACKGROUND

Godfrey (1982) describes the development and use of NVGs in military crewstations:

NVGs have now attained a level of sophistication such that aircraft can be safely and comfortably flown using these devices. NVGs operate by amplifying reflected low intensity visible and near infrared (invisible) light. The goggles most commonly referred to are AN/PVS-5 (Generation II) and ANVIS (Generation III) (Aviators Night Vision Imaging System). Generation II goggles can be helmet-mounted but are rather heavy and awkward. The user must see everything through them including cockpit instrumentation. The Generation II produces a bright target image at light levels as low as quarter moon illumination. The latest NVGs (Generation III) are helmet-mounted, lightweight, and well balanced so that the person wearing them can operate unhindered. The design permits use of the goggles to produce a clear green picture of the world around, while at the same time permitting use of the naked eye to look under the goggles and read instrumentation or other information. Generation III NVGs produce a bright target image at light levels as low as starlight illumination.

As with any new technology introduced into areas as complex as an aircraft crewstation, there are a number of problems which must be resolved. The most significant problem is the light which is enhanced to produce a picture of the outside world. The wavelength of this light is between 600 to 900 nanometers. This means that incandescent lamps or any other light whose wavelength is longer than approximately 525 nanometers (green light output) will also be amplified and interfere with the image of the outside scene. Yellows, reds, and infrared either "blind" the goggles or cause them to protectively shut down much as the unaided eye adapts to very bright light.

The response of the goggles used in this study are shown in Figure 1.

APPROACH

AAMRL approached the problem of flying very low levels, at night, by providing HUD symbols on a combining glass over one of the goggle eyepieces. The concept was to provide sufficient position and attitude information to allow an "eyes-out" orientation during special operations. Several modes of mission-oriented symbols were included as pilot options.

As shown in Figure 2, the AAMRL concept was to generate symbols based on digitized data from aircraft sensors, display the symbols on a CRT, and then focus the CRT image on a 400 x 400 element, fiber optic cable. The cable transmitted the image to a combining glass positioned in front of a single

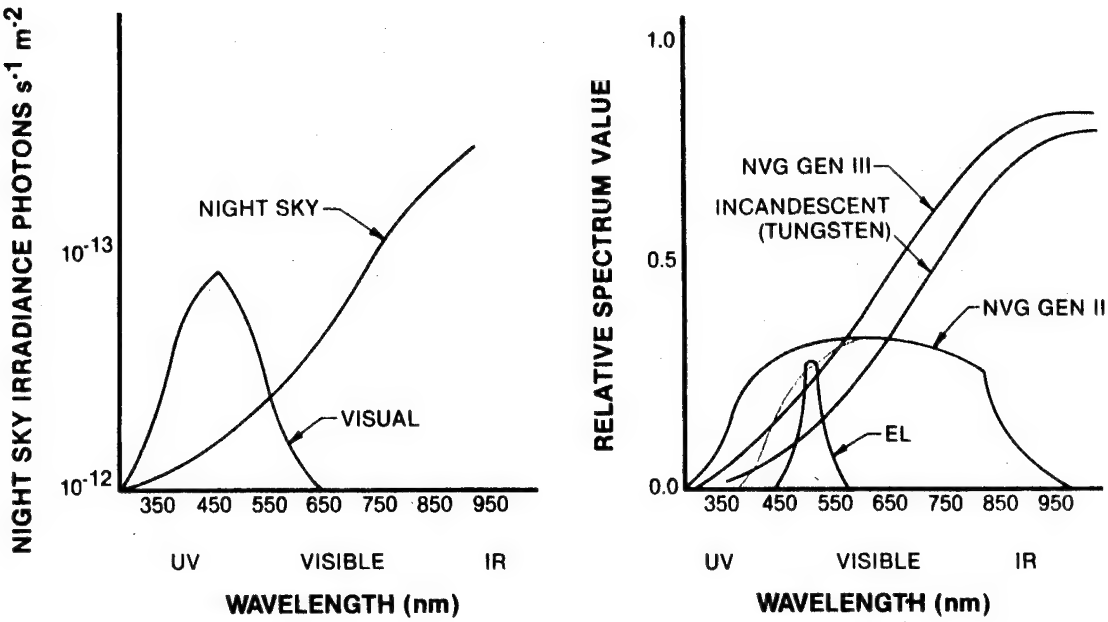


Figure 1. Response of Night Vision Goggles

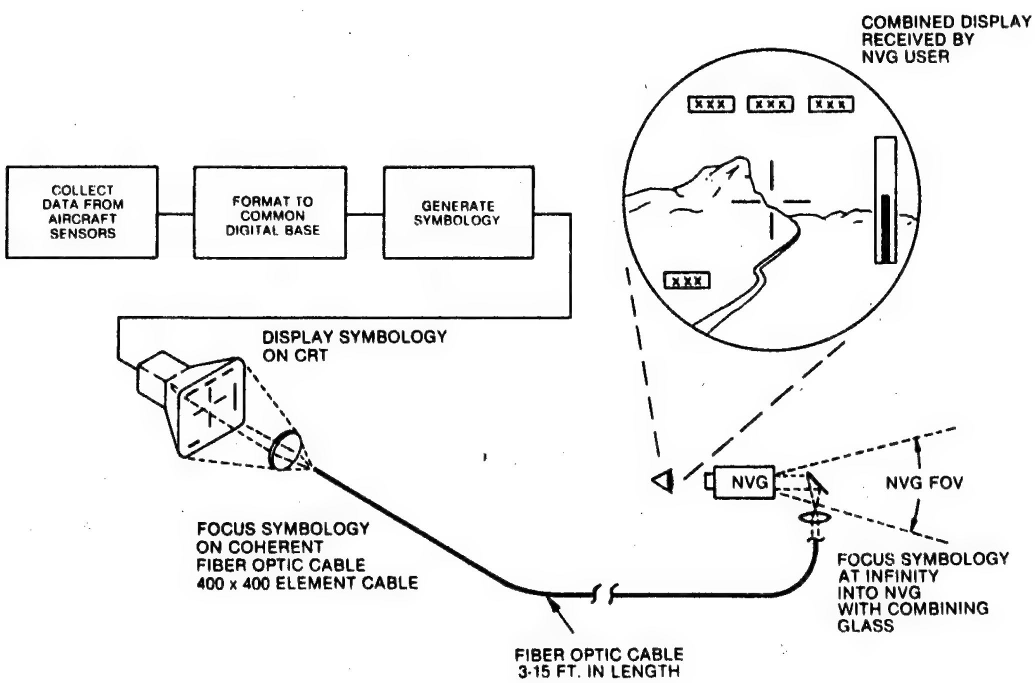


Figure 2. NVG/HUD Concept

NVG lens. The pilot's eye saw the symbols collimated at infinity, and within a wider field-of-view of an infrared image of the real world.

The overall approach was to select a feasible set of military standard HUD symbols and use actual OT&E flight experience with a demonstration device to obtain user modification requirements and acceptance information. For each aircraft test, pretest discussions were held with MAC personnel to derive a symbol set and control panel that appeared to satisfy the aircraft's mission requirements.

HQ MAC authorized the Operational Feasibility Test and Evaluation (OFT&E) of the NVG/HUD based on successful trials in preliminary C-141B flights:

> Operational incidents have highlighted the need to enhance the safety of night special operations missions. At HQ MAC/XPQ request, the AAMRL developed a HUD system for C-141B aircraft that is compatible with NVG use... The C-141B test results verified the usefulness and potential of the system to enhance C-141B special operations missions. (MAC Project Plan 15-84-84)

Over a 1-year period, MAC directed that NVG/HUDs be flown on the following aircraft:

C-141B	C-130E (AWADS)	HH-53H (PAVE LOW)
	MC-130E (TALON)	HH-53B/C (SLICK)
	AC-130 (GUNSHIP)	UH-60A (BLACKHAWK)
	HC-130P	

The AC-130 data were not available for this report and may be requested from AAMRL. The fixed-wing and rotary-wing aircraft used filtered incandescent, filtered electroluminescent (EL), and blue cockpit lights with blue secondary lights to achieve NVG use compatibility.

The test objectives listed in Table 1 were obtained from MAC test directives and personnel and included requirements for detailing hardware, software, training, and operational procedures. A special objective addressed the possible effects of levels of lunar (moon) illumination on NVG adequacy.

TABLE 1. TEST OBJECTIVES

- Determine usefulness and potential to enhance special operations.
- Develop symbols, symbol format for each aircraft (or mission mode when appropriate). Minimize the number of symbols, modes, and controls without compromising crew safety or adding to crew workload.
- Assess effects of night illumination.
- Develop control requirements.
- Determine compatibility with current mission equipment.
- Develop operational procedures.
- Quantify training requirements.

Section 2

METHOD

This section summarizes the mission planning factors, the NVG/HUD equipment, the experience levels of the crews, and the development of the questionnaires used for subjective ratings on system performance.

MISSION PLANNING FACTORS

The mission planning factors that affected NVGs during special low level flight usage are listed in Table 2.

TABLE 2. MISSION PLANNING FACTORS

	Factors		
Aircraft	Altitude (feet)	Airspeed (knots)*	Sortie Duration (hours)**
C-141B	500-1000	230-300	4
C-130E	500-1000	210-220	6-7
MC-130E	500-1000	210-220	6
AC-130H	6000	190-200	5
HC-130P	500-1000	210-220	5
HH-53H	50-500	60-130	4
HH-53B/C	50-500	60-130	4
UH-60A	50-500	60-150	2

SPECIAL MISSION REQUIREMENTS

- Air Drops
- Blackout Landings*
- Hover Operations
- Aerial Refueling
- Full Moon to No Moon Conditions
- 3000-Foot Ceiling, 3 nm Visibility Minimums
- Covert Operations, Operating With Minimum Number of Internal and External Lights Set at Lowest Intensities

*Excludes hover airspeeds.
**Excludes in-flight refueled sorties.

NVG/HUD EQUIPMENT

The equipment configuration designed for the flight demonstration is shown in Figure 3 and is described in more detail in Appendix A. The symbols used for each aircraft evaluation are shown in the questionnaires (Appendix B) and drawings of the final symbol sets proposed for fixed-wing and rotary-wing aircraft are shown in Figures 20, 21, 22, and 23.

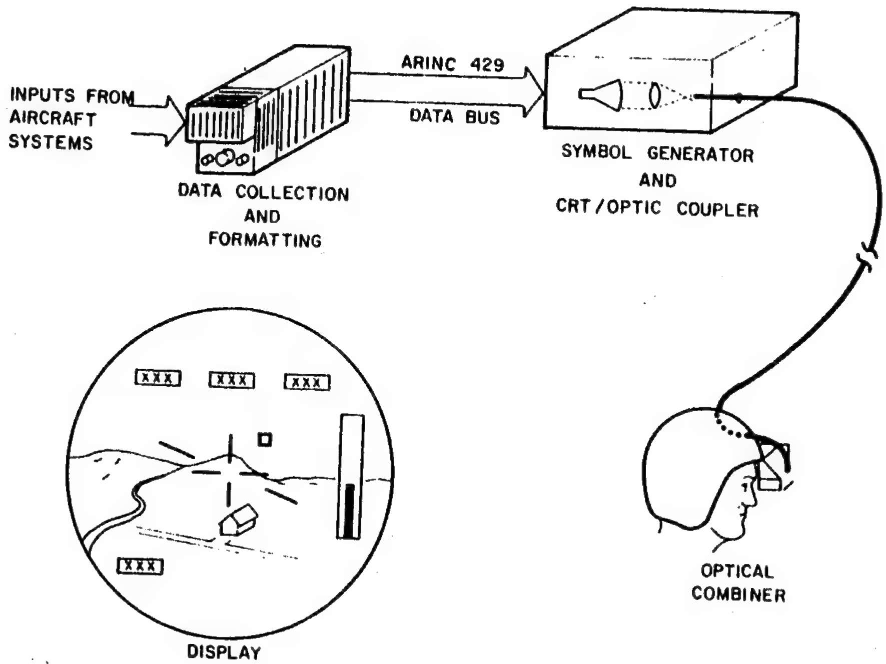


Figure 3. NVG/HUD Configuration

The flight instrument raw signal information was collected by the aircraft's signal processing computer, converted into Arinc 429 formatted data, and transmitted to the display. The display unit converted the data to a symbolic display on a cathode-ray tube format. The symbology display was reflected from a front surface mirror to a relay lens which focused the image onto a flexible fiber optic bundle. The bundle transmitted the image to the NVG where a collimating lens moved the symbol image to optical infinity. This image was then reflected from a beam splitter into the NVGs. The observer viewed the image of the HUD symbols superimposed over the outside view.

Several modes of mission oriented information were included as pilot options. Figures 4 and 5 shows the HUD symbols selected for the transport and helicopter flights. Generally, for modes such as SEARCH and LANDING, the number of symbols was reduced to avoid cluttering the center of the IR image when the pilot is concentrating on ground patterns and landmarks.

Some examples of special features of the symbology are listed in Table 3 and were varied for several of the aircraft.

The final control panel used by the pilots is shown in Figure 6. The panels were positioned at various cockpit locations, depending on the type of aircraft. A design goal was to include only critical pilot control functions and automate other functions (e.g., focus, contrast).

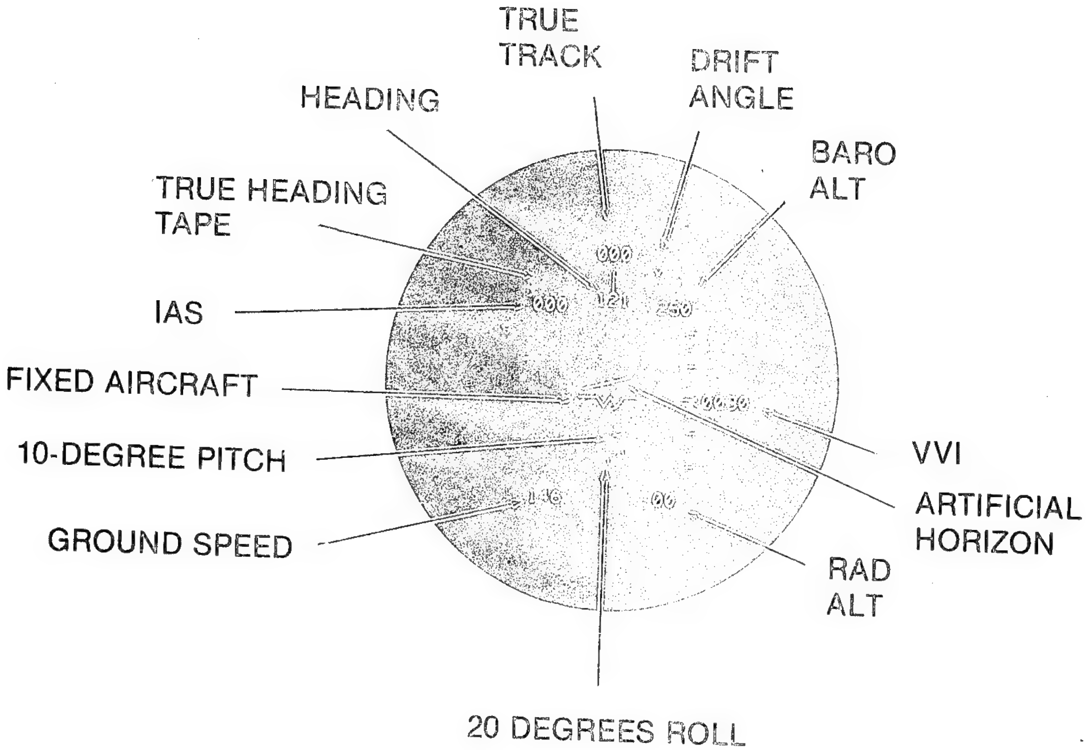
CREW EXPERIENCE

Table 4 summarizes the flight experience level of the pilots used in the study. The data are incomplete because of incompleted questionnaires.

The number of pilots fully qualified in several MAC special operations units is very small. For example, the six C-141B aircraft commanders (ACs) listed in Table 4 represented the majority of the total C-141B ACs qualified for this mission. In general, the pilot population was highly experienced in total flight time, time in the aircraft, and (except for combat) time with the mission.

QUESTIONNAIRES

The same MAC questionnaire (Appendix B) was used to obtain pilot experience and comments on mission adequacy and training requirements. Several AAMRL developed questionnaires (Appendix B) were used to obtain five-point ratings and comments on symbols, symbol characteristics, symbol modes and controls, and was tailored, where appropriate, for each aircraft. [For this report, the term "mode" means the display of a symbol set for a portion of a mission (e.g., enroute mode, landing mode)]. The results from the questionnaires



ENROUTE LANDING

Figure 4. HUD Symbols Used for Fixed-Wing Flights

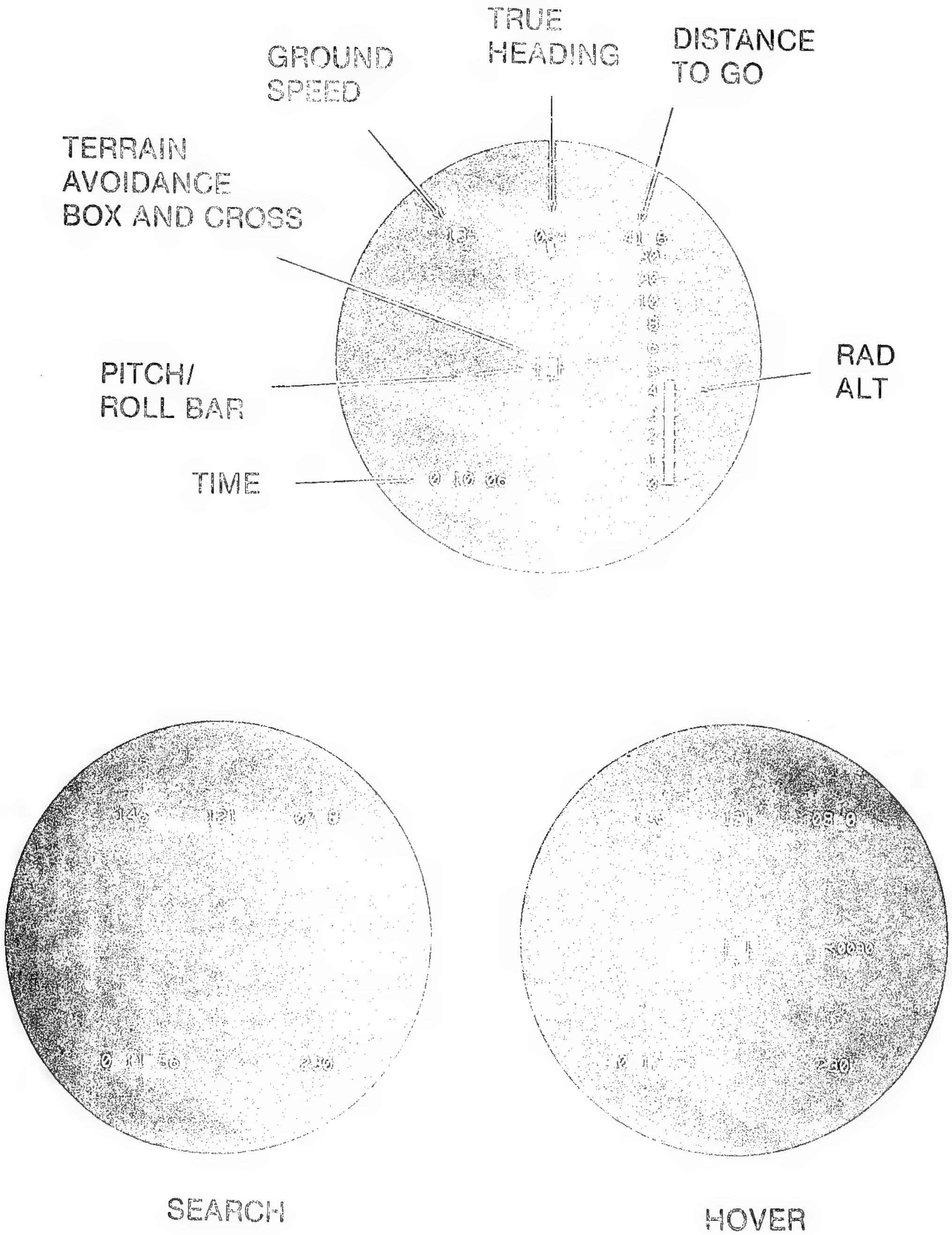
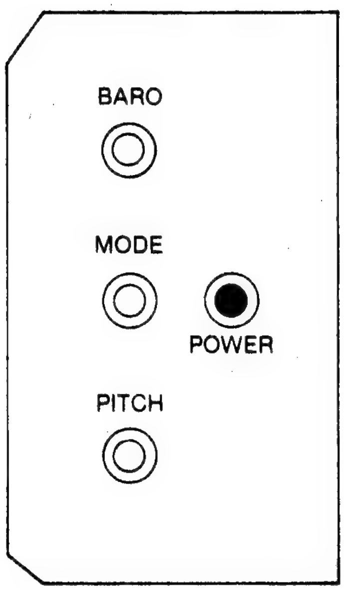


Figure 5. HUD Symbols Used for Rotary-Wing Flights

TABLE 3. SPECIAL SYMBOL FEATURES

Altitude	Displays barometric or radar altitude, radar changes in 10-foot increments below 1000 feet, 100-foot increments above 1000 feet.
Fixed Digit	The last zero for altitude and vertical velocity is an unchanging zero (0) to reduce distraction of a fast changing digit.
Pitch	Over 10 degrees of pitch, a 10's digit is displayed to the left of the aircraft and 1's unit to the right.



4 PUSHBUTTONS

BARO - Selects barometric pressure

MODE - Selects symbol set for mission segment

POWER - Turns HUD equipment ON

PITCH - Trims the aircraft symbol to horizon bar for pitch reference

1 RHEOSTAT (not shown, mounted on helmet)

BRIGHTNESS - Changes symbol brightness

Figure 6. NVG/HUD Controls

are presented in Table 4 (Pilot Experience), for each type of aircraft in Section 3 (Results), and in greater detail in Appendix C.

TABLE 4. PILOT EXPERIENCE

	C-141B	C-130E	MC-130E	AC-130	HC-130P	HH-53H	HH-53B/C	UH-60A
Number of Pilots	6	5	7	1	2	5	2	2
Crew Positions								
FEAC		2				1		
IP		2	2			1		
Pilot		1	3			3		
Total Flight Hrs (mn)*		2350	1866		950			
Months NVG Qualified (mn)			20					
**SOLL II Flight Hrs (mn)		250						
Months SOLL II Qualified (mn)		21						

* (mn = average mean)

**Special Operations Low Level II includes the use of NVGs for night airdrops and landings under blackout conditions.

Section 3
RESULTS

This section summarizes the pilots' comments on the NVG/HUD system and their recommendations for system modifications and procedures for operating the equipment. The data are presented as average ratings (mean = sum of ratings/n of respondents) individually for each aircraft, in the order the aircraft were flown.

For purposes of brevity, the crew's comments on symbol characteristics have been summarized in Figure 9. Additional pilot ratings and comments have been included in Appendix C. The crew's terms for symbols (e.g., heading, track, and mag heading) were retained for the report.

Generally, the fixed-wing and rotary-wing pilots use NVGs to maintain an outside scan while the copilots scan inside and ensure the integrity of aircraft velocity and attitude. Navigators and third pilots may share inside and outside vigilance duties in fixed-wing aircraft and verbally provide critical airspeed, altitude, and range values to the pilot.

C-141B FLIGHTS

The four-engine C-141B heavy jet transport flies Special Operations Low Level II (SOLL II) missions that include night, blacked-out airdrops or landings, and takeoffs from remote fields with three pilots, two of them wearing NVGs.

The fixed-wing questionnaire (Appendix B) was used to obtain the pilot ratings shown in Figure 7.

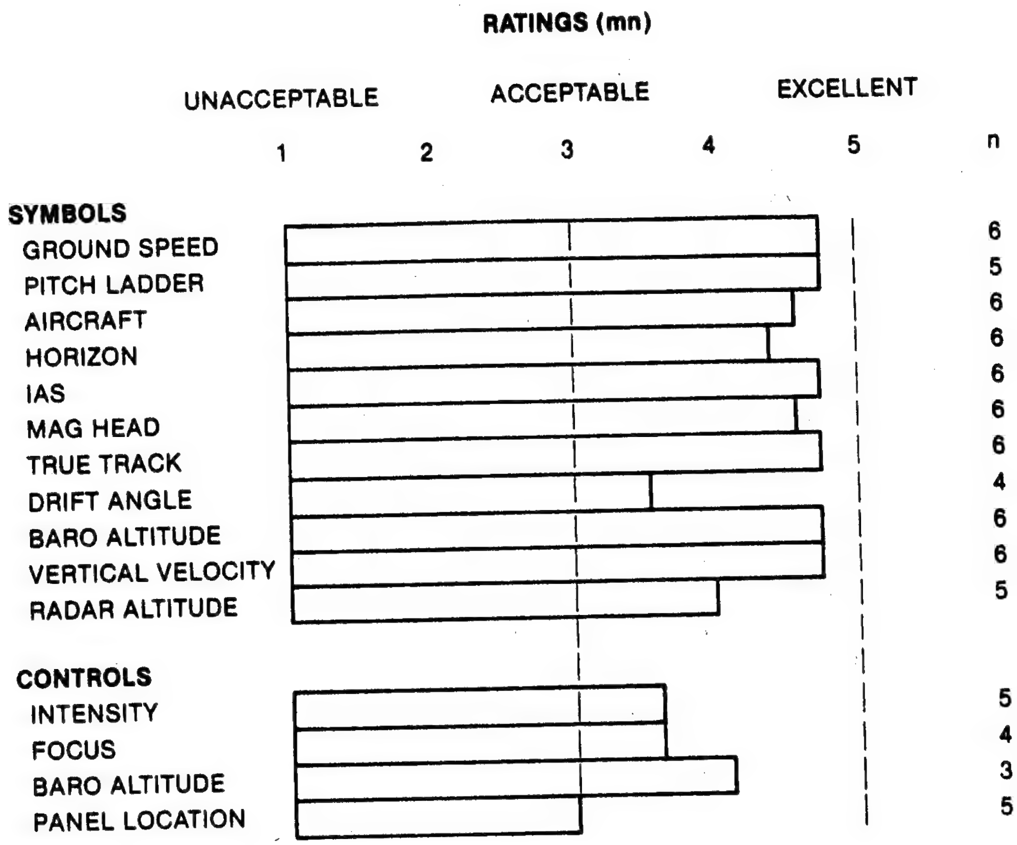


Figure 7. C-141B Pilot Ratings of Symbols and Controls (Total n=6)

Using the five-point rating scale, the HUD symbols were rated as being between "more acceptable" and "excellent" except for the drift angle symbol. The three system controls (to adjust intensity and focus and to reset the barometric altimeter) were rated as more than acceptable. The location of the control panel was rated acceptable; however, its relocation was also recommended. Visual fatigue was rated as below average to none and display contrast as being adequate for most night sky conditions under various levels of illumination. In terms of the system's contribution to mission success, the pilots generally agreed that the NVG/HUD enhanced control of the aircraft, reduced interphone communication and increased flight safety (terrain clearance).

C-130E FLIGHTS

The C-130E is an extended range version of the C-130B with large underwing fuel tanks and is equipped with an Adverse Weather Aerial Delivery System (AWADS).

In addition to ratings on symbols and controls, ratings were obtained on symbol sets for three mission modes for the rest of the aircraft in this report. Figure 8 presents the ratings of adequacy of NVG/HUD symbols and controls and Figure 9 presents the ratings on mode symbols.

Four pilots rated the drift angle symbol as acceptable but did not use it and recommended deleting it in the operational system. The aircraft symbol size was considered too small to be seen separate from the horizon symbol and preferred a new shape (or   ) that was closer to the ADI symbol. The vertical velocity symbol was rated as desired but its movements during the flight were erratic and unreliable. For the standard and enroute modes, the sky pointer was considered superfluous, and IAS was recommended to replace TAS. Critique of the landing mode included comments on deleting the mode, replacing it with the normal mode, and deleting mag heading and the lubber line. Two pilots recommended enlarging the symbol area ("doubling it") for easing readablilty. Control panel location in the cockpit was considered acceptable; however, one pilot suggested moving it to the forward end of the pilot's left control panel. All of the controls were rated near excellent, and one pilot recommended moving the mode pushbutton to the top of the panel because it is the most used control.

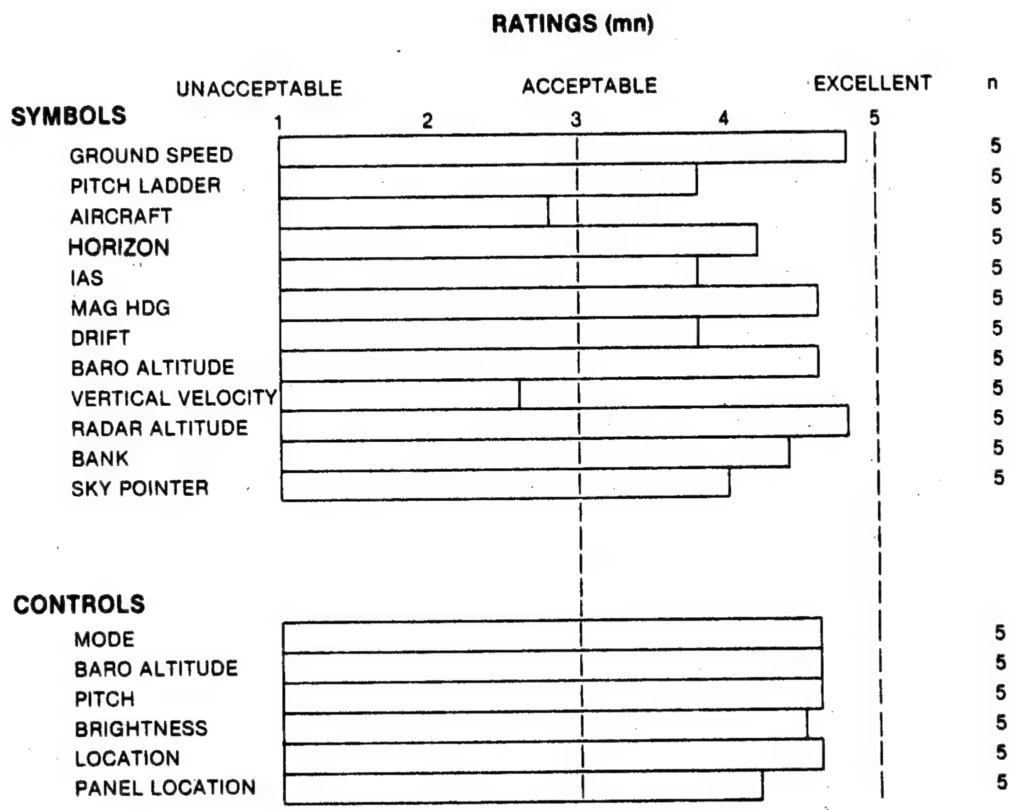


Figure 8. C-130E Pilot Ratings of Symbols and Controls (Total n=5)

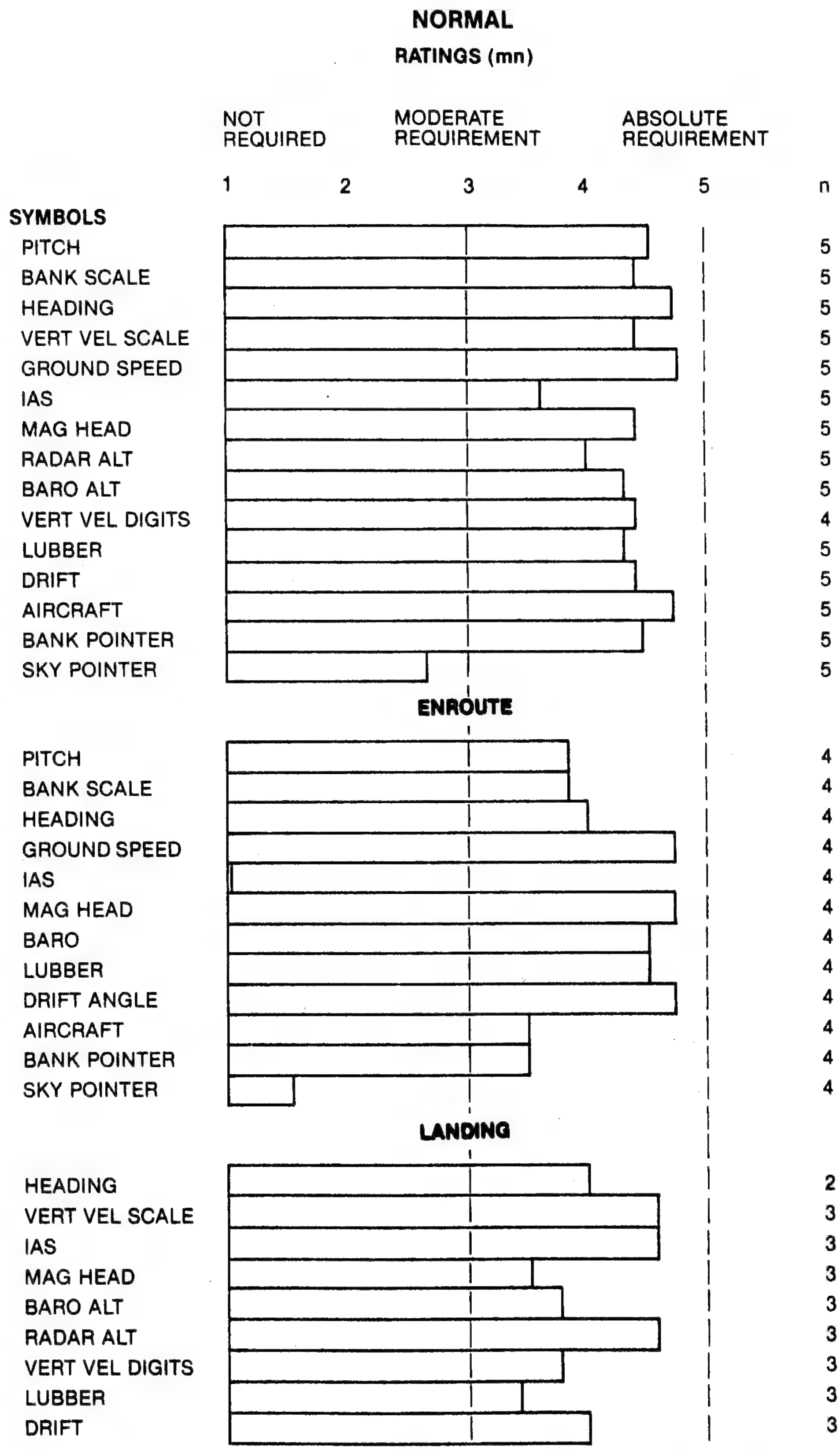


Figure 9. C-130E Pilot Ratings of Symbol Modes (Total n=5)

MC-130E FLIGHTS

The MC-130E (Combat Talon) aircraft is a low level penetration version of the C-130E. The fifteen aircraft are flown by special operations squadrons based in the Philippines, West Germany, and Florida.

Figures 10 and 11 present the MC-130E pilot ratings on symbols, modes, and controls. The MC-130E pilots rated symbol, symbol sets, and controls lower than the other aircraft pilots in this study. Several pilots suggested deleting the drift, sky pointer, lubber line, baro alt, vertical velocity, and bank angle scale symbols. The enroute mode was recommended for deletion and AGL replaced with the MSL symbol. Magnetic heading, lubber line, baro alt, and vertical velocity symbols were recommended for deletion in the landing mode. The control panel (and particularly the mode control) was recommended for placement nearer to or on the control yoke. The need for a pushbutton method of controlling baro alt and pitch were rated low. The location of the brightness control (on the helmet) was a problem for some pilots. Washout of the image from ground lights during a short final; excessive eye fatigue from changing focus between symbols and field; some restraint of head movement from the helmet; integration of INS inputs for navigation; and possible body movement problems in an emergency were mentioned by the pilots.

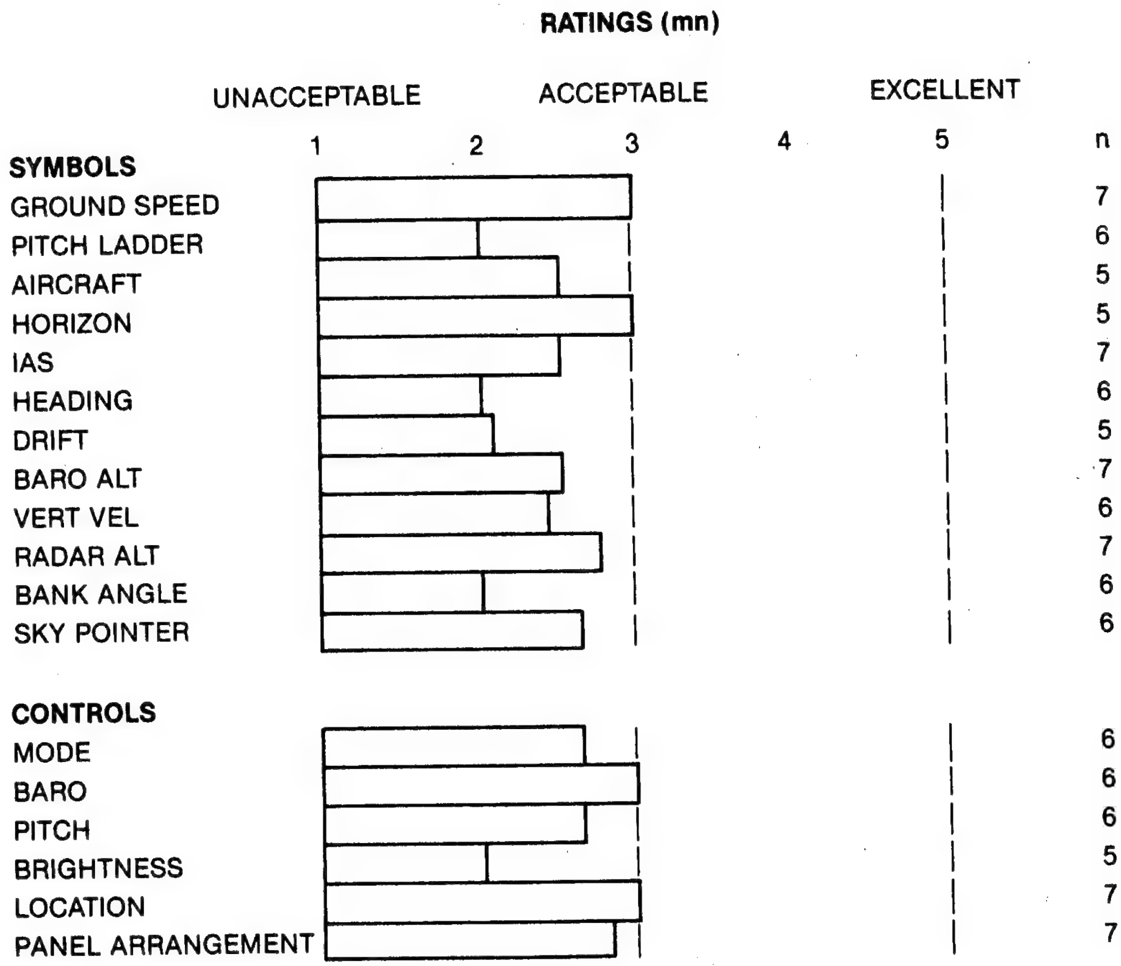


Figure 10. MC-130E Pilot Ratings of Adequacy of Symbols and Controls (Total n=7)

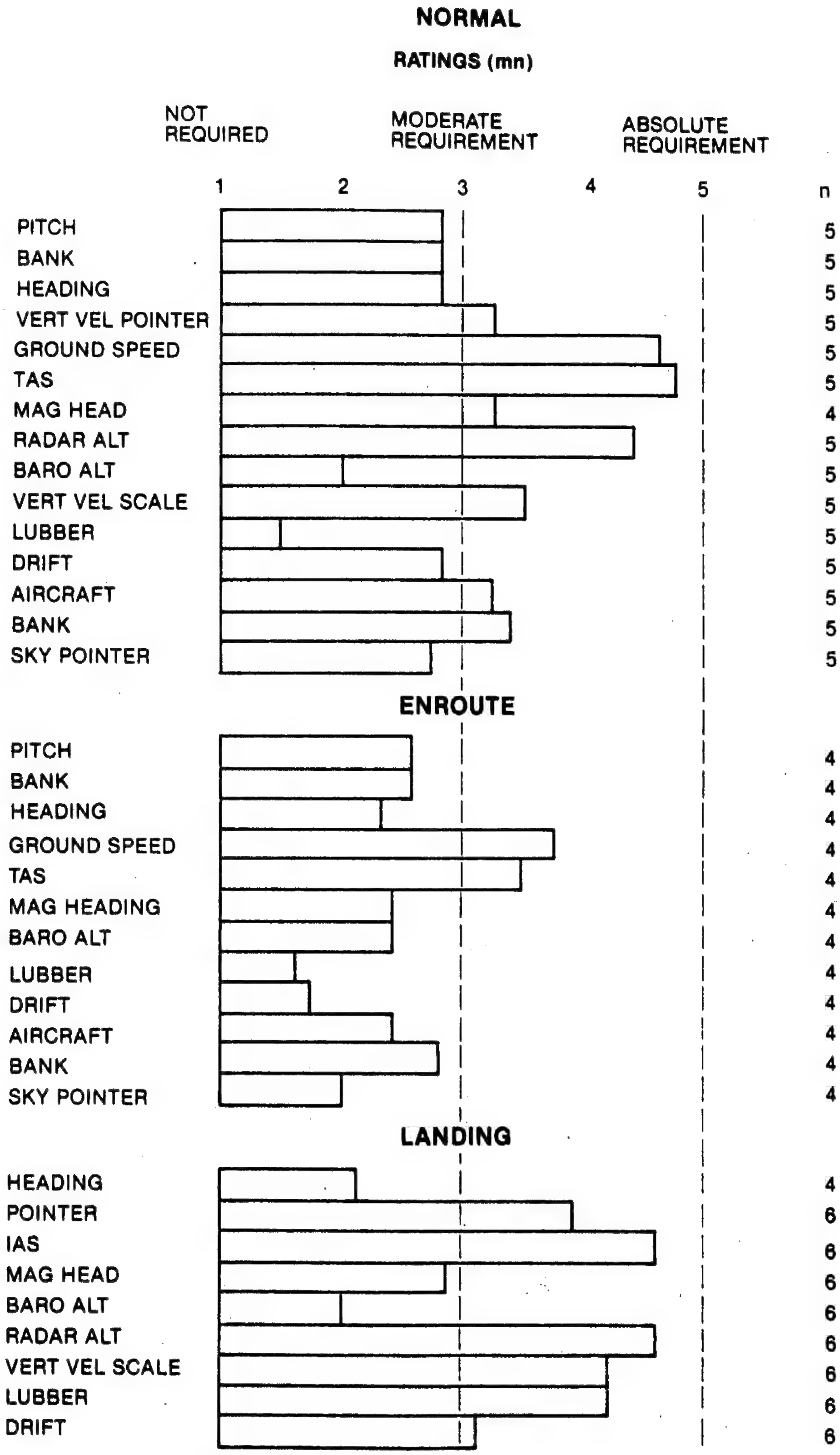


Figure 11. MC-130E Pilot Ratings of Symbol Modes (Total n=7)

AC-130 FLIGHTS

The data from these flights were not available and are not reported in this study. Queries for these data should be addressed to Jeffrey Craig, AAMRL.

HC-130P FLIGHTS

The HC-130 is an extended range version of the C-130 with upgraded engines and specialized search and rescue equipment for the recovery of aircrews. Twenty HC-130s were modified to HC-130Ps for refueling helicopters in flight.

Figures 12 and 13 present the HC-130P pilot ratings on symbols, modes, and controls. The sky pointer and lubber line were recommended for deletion and increased size recommended for the bank angle, horizon, and drift symbols. Triangles (▲) were suggested for the sky pointer and bank angle symbols. One of the two pilots did not use the mode, baro, or pitch pushbuttons and both pilots recommended dual controls for brightness.

Possible problems in moving around the cockpit in an emergency, the need for checklist calls for mode selection, and display tuning problems were mentioned by the pilots.

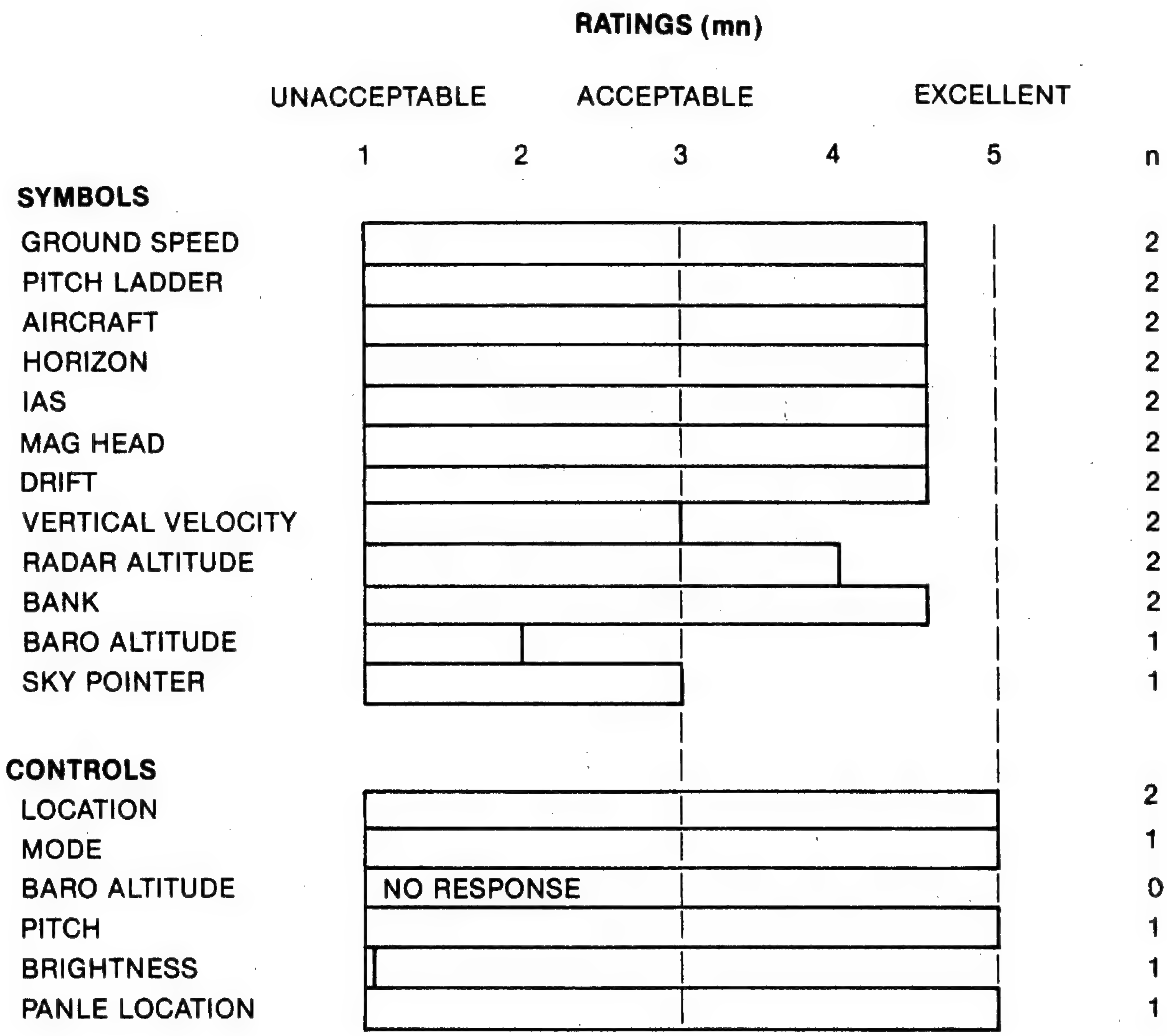


Figure 12. HC-130P Pilot Ratings of Symbols and Controls (Total n=2)

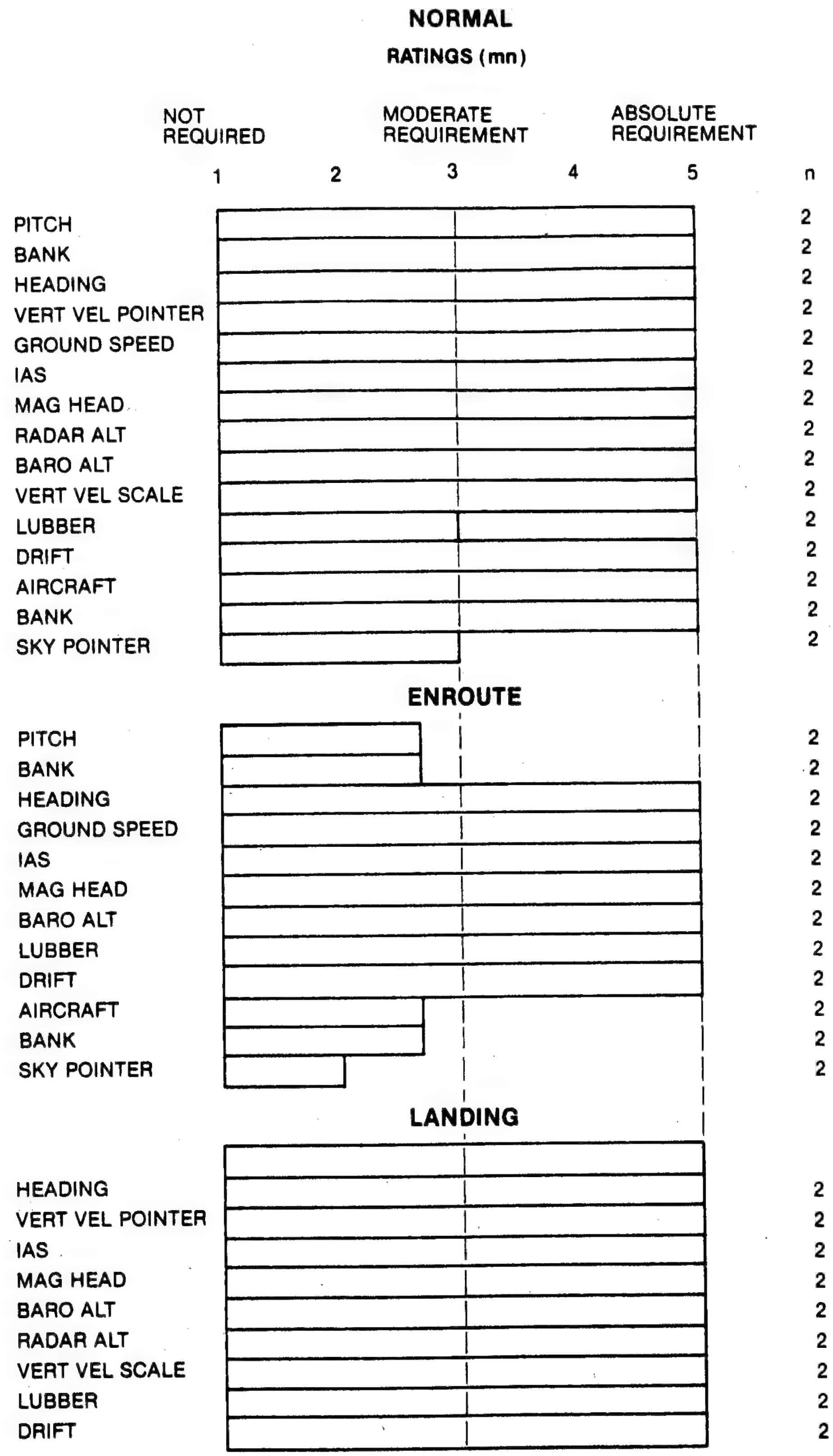


Figure 13. HC-130P Pilot Ratings of Symbol Modes (Total n=2)

HH-53H FLIGHTS

Nine HH-53Cs were modified to HH-53H aircraft (PAVE LOW) for night and adverse weather operations. Their equipment includes a stabilized forward-looking infrared (FLIR) system, an inertial navigation system, a new Doppler navigation system, and a computer projected map display and radar from the A-7D.

Figures 14 and 15 present the HH-53H pilot ratings of symbols, modes, and controls. The time-to-go, ground speed, true heading, and distance-to-go were rated as being too small. Again, for all of the modes, many of the symbols were rated as being too small in size. Ground speed, true heading, steering, and radar altitude were rated as the most required symbols. Inadequacy of display when looking toward brightly lighted areas; relocation of symbols to edge of display; need for symbols focused at infinity; eye strain helped by changing intensity, relief of workload; being able to turn off the bright FLIR display and reduce cockpit illumination; rotation of the NVG tube in the direction of the hanging bundle; and location of the mode select on the cyclic stick were reported by the pilots.

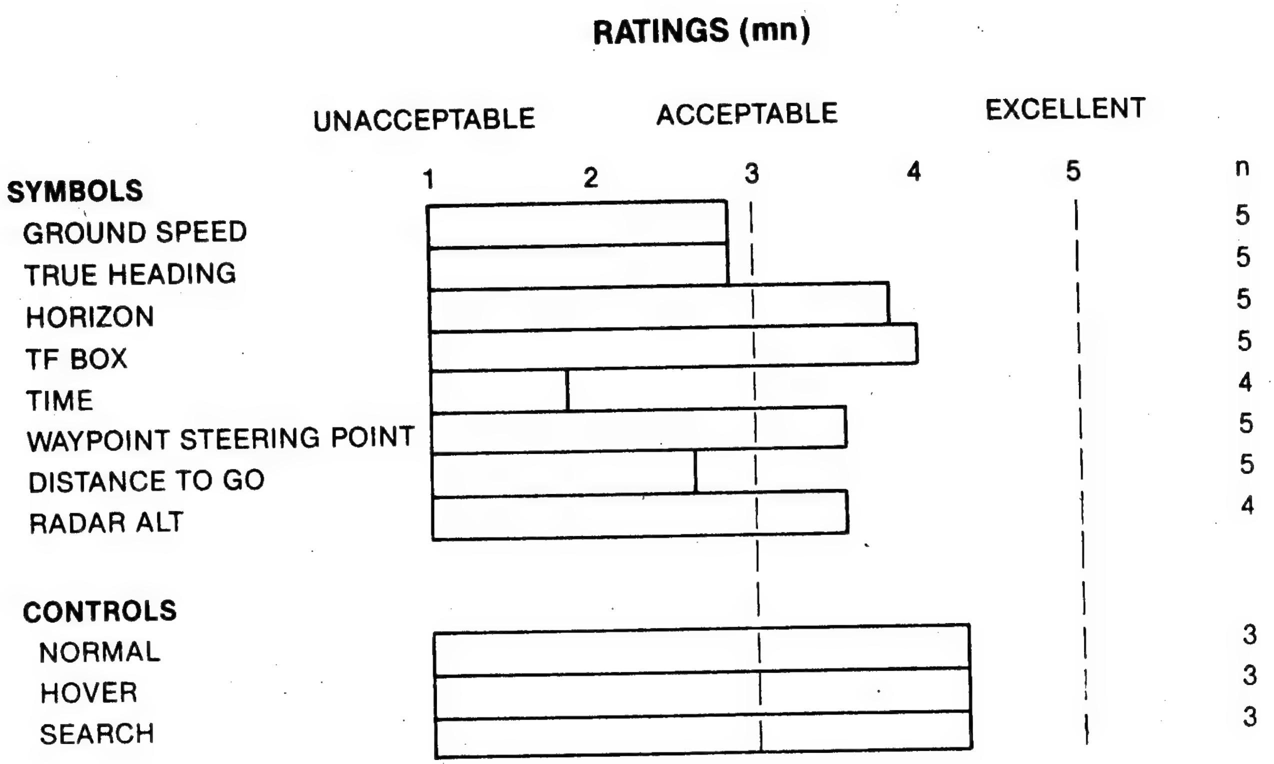


Figure 14. HH-53H Pilot Ratings of Adequacy of Symbols and Controls (Total n=5)

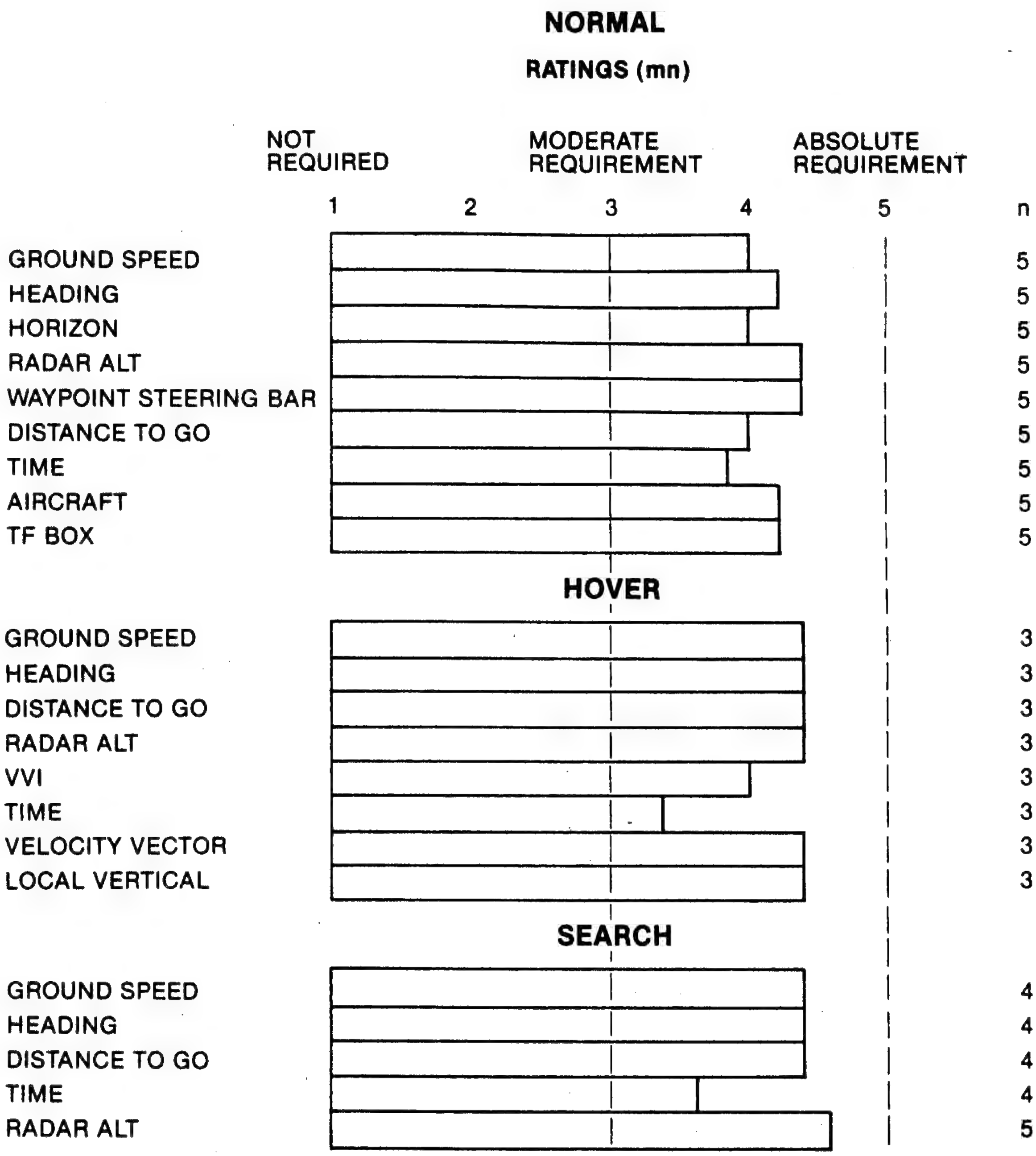


Figure 15. HH-53H Pilot Rating Symbol Modes (Total n=5)

HH-53B/C FLIGHTS

The HH-53B twin turbine heavy lift helicopter was ordered for the rescue and recovery service. It has all-weather avionics and armament and is faster and larger than the Jolly Green HH-3Es. The helos can carry 38 passengers at 170 knots.

Figures 16 and 17 present the HH-53B/C pilot ratings on symbols, modes, and controls. Based on two pilot subjects, the ground speed, mag heading, distance-to-go, and radar altitude symbols were rated as being too small in vertical size. The velocity vector and steering bar symbols were inoperative and not rated. Time-to-next-waypoint was rated as not needed in the hover mode. The mode pushbutton was recommended for a yoke location. Magnetic heading and radar altitude were rated as the most required symbols.

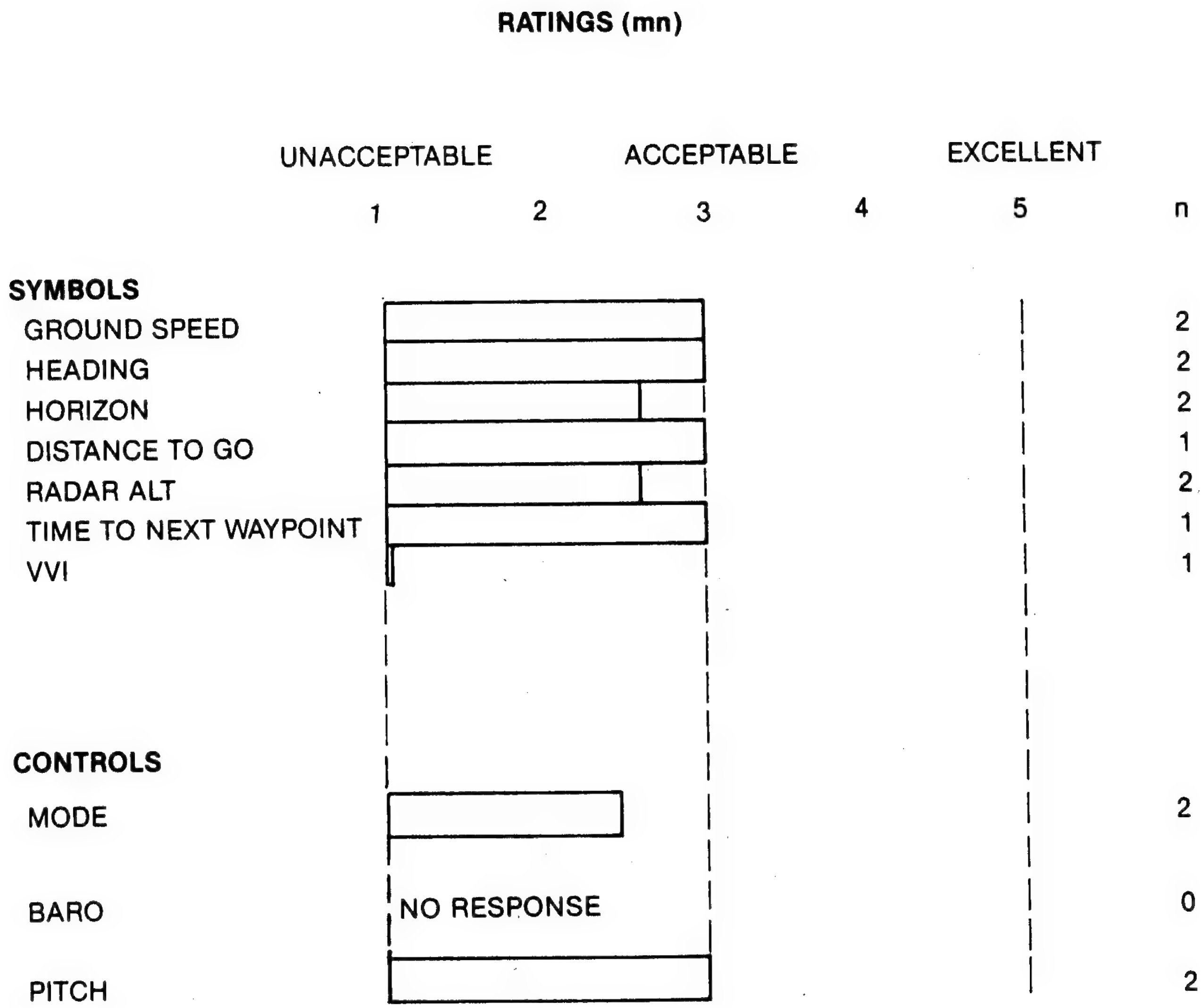


Figure 16. HH-53B/C Pilot Ratings of Adequacy of Symbols and Controls (Total n=2)

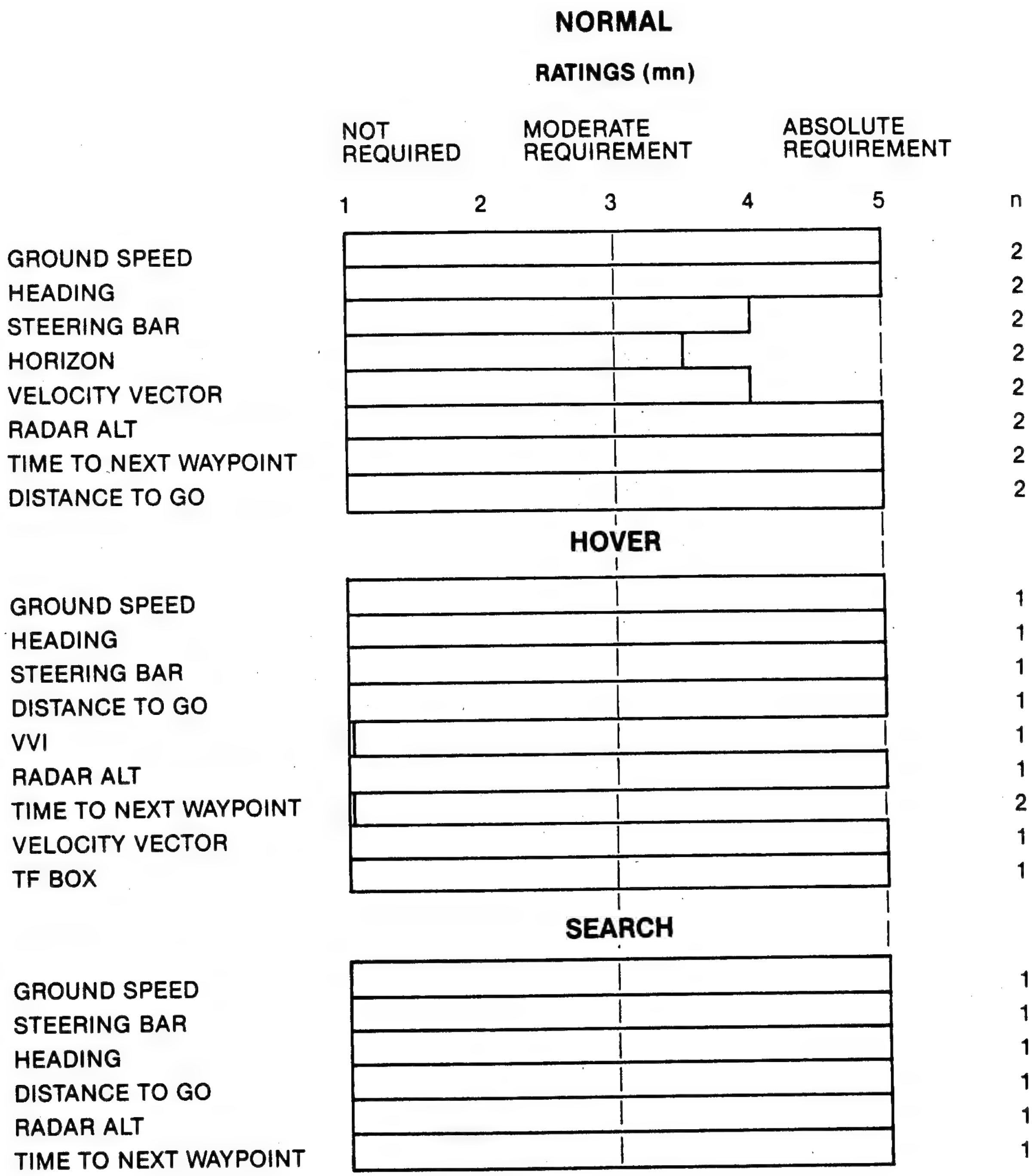


Figure 17. HH-53B/C Pilot Ratings of Symbol Modes (Total n=2)

UH-60A FLIGHTS

The Blackhawk is a twin turbo powered, 184 mph, 11 passenger helo equipped with standard U.S. Army configurations for conducting special operations missions deep behind enemy lines, in darkness or bad weather, and at treetop level.

Figures 18 and 19 present the UH-60A pilot ratings on symbols, modes, and controls. Both of the UH-60A pilots recommended larger ground speed, time, and distance-to-go symbols. Scale changes of radar altitude were suggested for hover and search modes. IAS was recommended rather than ground speed for normal and search modes and not required for the hover mode. Real-time in Zulu and deletion of VVI in hover were suggested. Heading, distance-to-go, and the steering bar were rated as the most required symbols. Slight eyestrain; need for VVI information; movement of the power cord; lag in bank angle response of the symbol; and "spreading out" of the symbol array was mentioned by the pilots.

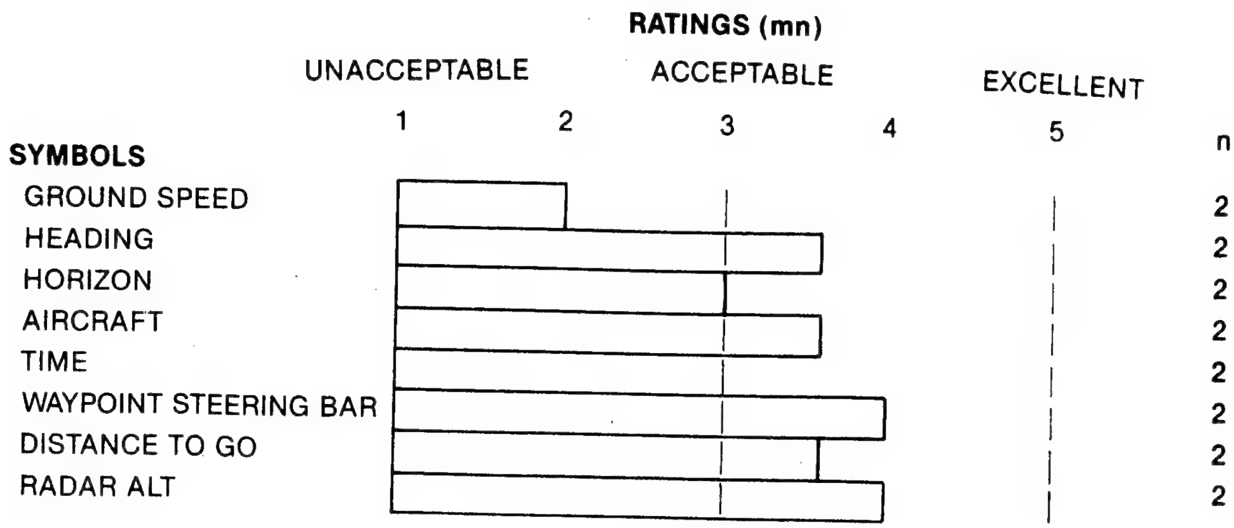


Figure 18. UH-60A Pilot Ratings of Symbols and Controls (Total n=2)

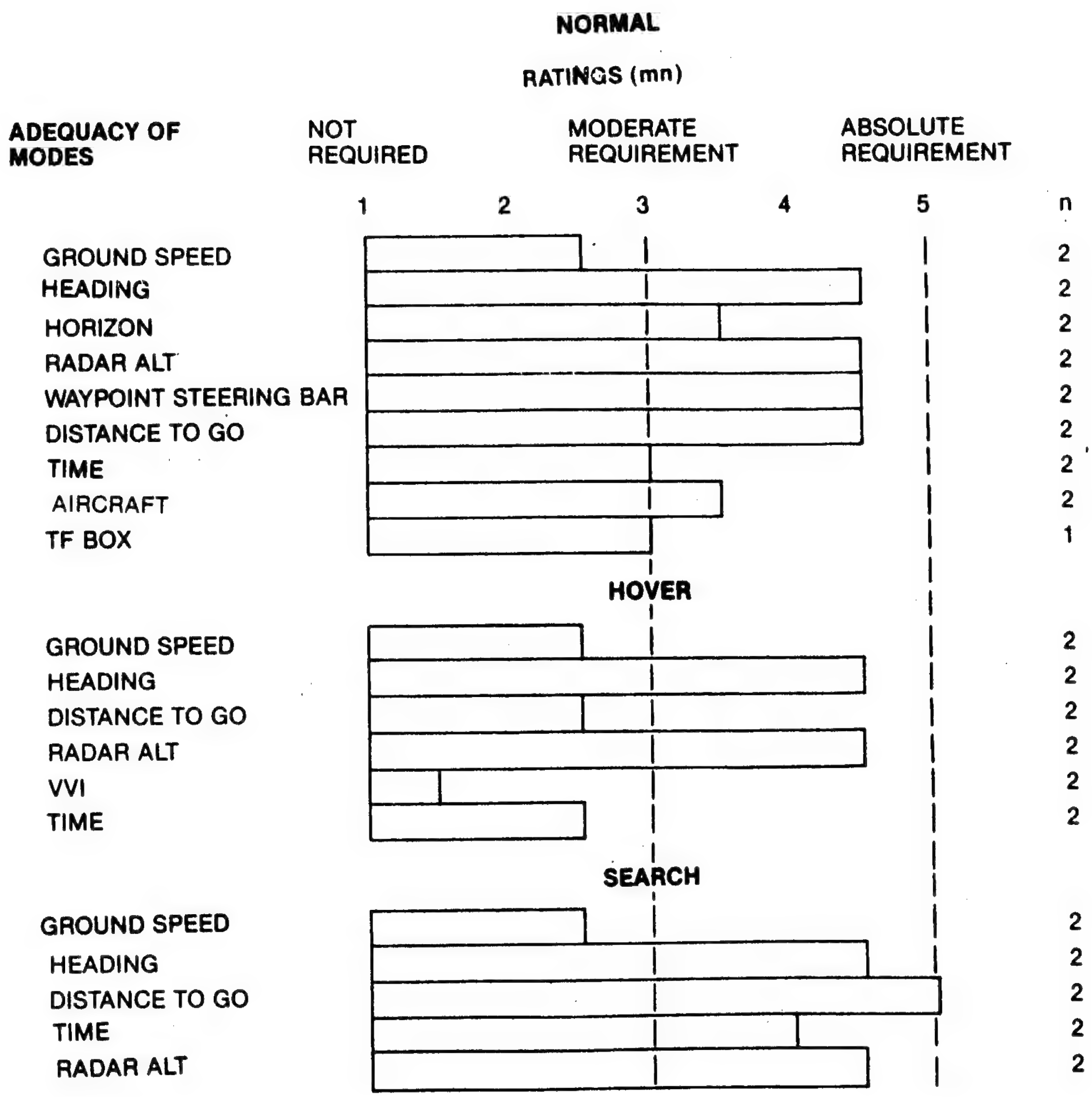


Figure 19. UH-60A Pilot Ratings of Symbol Modes (Total n=2)

SYMBOL CHARACTERISTICS FOR ALL FLIGHTS

For brevity and comparisons, ratings on symbol characteristics for all of the aircraft are included in Table 5. Symbol characteristic ratings were not obtained for the first aircraft, the C-141B, and the data were not available for the AC-130 aircraft.

Insufficient size of some symbols (e.g., ground speed, drift), deletion of some symbols for some modes (e.g., vertical velocity, sky pointer), shape and size of the fixed aircraft symbol, size and location of the distance-to-go symbol, and shape/size/scale rate of movement for the bank angle symbol were rated for changes. However, such recommendations may be specific to the type of aircraft and its special mission requirements, as well as differences between the visual information requirements for fixed-wing and rotary-wing aircraft at various airspeeds (0 to 300 knots). A high number of "no change" responses can be interpreted as being firm symbol requirements for an aircraft.

TABLE 5. RATINGS ON SYMBOL CHARACTERISTICS (ALL AIRCRAFT)

(Total n)	C-130E (5)		MC-130E (7)		HC-130P (2)		HH-53H (5)		HH-53B/C (2)		UH-60 (2)	
Would You Change	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Ground Speed												
Size		5		6		2	3		1	1	2	
Location		5	2	4		2		2	1	1	1	1
Width							1	1		2		1
Movement		5		6		2	1			2		1
Add a Scale		5		6		2		2		2		1
Delete		5	1	4		1		2		2		2
Mag Heading												
Size		5	2	4		2			1	1		
Location		5	3	3		2			1			
Width										1		
Delete		5	1	4		2				1		
Scale Movement		5	1	5		2						
Delete the Scale or			4	2		2						
Lubber Line		5										
Add a Label	1	4	1	3		2						
Heading												
Size							4				2	
Location							1	1			1	1
Width								2				1
Delete								2				2
Pitch Ladder												
Internal		5	1	2		2						
Length of Steps		5	1	2		2						
Number of Steps		5	1	2		2						
Label Steps	2	3		3	1	1						
Aircraft												
Change Shape To												
	1	5										
		5										
		5										
		5										
	1	5	1									
	4	1	2			2						
Horizon												
Size								1		2	1	1
Width	1	4		3	2			1		2	1	1
Location								1	1	1	1	1
Movement		4	1	2		1			1	1		2
Delete								1		2		

TABLE 5. RATINGS ON SYMBOL CHARACTERISTICS (ALL AIRCRAFT) (continued)

	C-130E		MC-130E		HC-130P		HH-53H		HH-53B/C		UH-60	
(Total n)	(5)		(7)		(2)		(5)		(2)		(2)	
Would You Change	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
TF Command												
Size								1				
Shape								1				
Location								1				
Movement								1				
Delete								1				
IAS												
Size		5				2						
Location		5				2						
Add a Scale		5				2						
Movement		5			1	1						
Add a Label	1	4				1						
Delete	1	4				2						
TAS Symbol												
Size			1	3								
Location			3	1								
Add a Scale			2	4								
Movement				3								
Add a Label			1	3								
Delete				3								
Add a Scale												
Movement												
Add a Label												
Delete												
Drift												
Shape		5	1	2		2						
Size		5	1	2	1	1						
Scale		5	1	2		2						
Movement		4	1	2		2						
Delete		4	1	2		2						
Distance to Go												
Size							4			1	2	
Shape								2	1			2
Location							2	1			2	
Width								2				2
Delete								2		1		2

TABLE 5. RATINGS ON SYMBOL CHARACTERISTICS (ALL AIRCRAFT) (continued)

	C-130E		MC-130E		HC-130P		HH-53H		HH-53B/C		UH-60	
(Total n)	(5)		(7)		(2)		(5)		(2)		(2)	
Would You Change	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Bar Altimeter												
Size		5		4		1						
Location		5	2	3		1						
Movement		5		3	1							
Add a Scale		5	1	3		1						
Add a Label	1	4	1	3		1						
Delete		5	1	3		1						
Vertical Velocity												
Scale	1	4	2	1		2						
Pointer		5	2	1		2						
Digit Size		5	2	1		2						
Location		5	2	1		2						
Digit Movement	2	3	1	2	1	1						
Pointer Movement	3	2	3			2						
Delete Decimal	2	2	3		1	1						
Delete Heading	2	2	2			2						
Velocity Vector												
Size												
Shape												
Location												
Box Movement												
Delete Vector												
Delete Box												
Radar Altimeter												
Size		5	1	5		2	1			2		2
Location		5	3	4		2			1	1	1	1
Width										2		2
Add a Scale		5	1	5		2			2		1	1
Movement		5	3	3	2					1		2
Add a Label	1	4	1	5		2				1		2
Delete		5		5		2		1		2		2
VVI												
Size												
Location												
Delete												
Time to Next Waypoint												
Size										1		
Location									1			
Delete										1		

TABLE 5. RATINGS ON SYMBOL CHARACTERISTICS
(ALL AIRCRAFT) (continued)

	C-130E		MC-130E		HC-130P		HH-53H		HH-53B/C		UH-60	
(Total n)	(5)		(7)		(2)		(5)		(2)		(2)	
Would You Change	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Time												
Size							3				2	
Shape								1				2
Location							1	1			2	
Width								2				2
Delete								2				2
Aircraft												
Size											1	1
Shape											1	1
Location											1	1
Movement											1	1
Delete												2
Waypoint Steering Point												
Size								2				1
Shape								2				2
Location								1				2
Movement								2				2
Width							1	1				2
Delete								2				2
Bank Angle												
Shape		5	1	2	1	1						
Size		5	2		2							
Scale		5	3			2						
Rate of Movement		5	1	2		2						
Add a Label	1	4		3		2						
Delete		5	1	2		2						
Sky Pointer												
Shape		5		2	1							
Size		5		2	1							
Scale		5		2								
Movement		5		2								
Delete	2	3	2	2	1							

Section 4
CONCLUSIONS

This section addresses the fulfillment of the seven test objectives listed in Table 1. Also, some recommendations are made for considering the use of the device for other aircraft and missions.

In general, the pilots accepted the device as favorably affecting mission success, wanted larger symbols, recommended relocating the symbols to the edge of the field-of-view, and changing the symbol focus to infinity; and some fixed-wing and rotary-wing pilots suggested a two-mode rather than three-mode concept. The two-mode concept (Figures 20 through 23) were proposed as final prototypes for fixed-wing and rotary-wing aircraft.

USEFULNESS OF NVG/HUD FOR SPECIAL OPERATIONS (OBJECTIVE 1)

The pilots rated the NVG/HUD as being useful for improving mission performance as follows;

	IMPROVING MISSION PERFORMANCE	
Aircraft	Yes	No
Fixed-Wing	8	1
Rotary-Wing	7	0
	15	1

and included the major advantages and disadvantages shown below (rank ordered for frequency of response):

Advantages of Using NVG/HUD	Fixed-Wing (n)	Rotary-Wing (n)
Approaches and Landings	8	1
Night Navigation	5	2
Increases Safety	4	1
Better Control of Aircraft	3	
Everything		3
Air Drops	1	
Hover		1

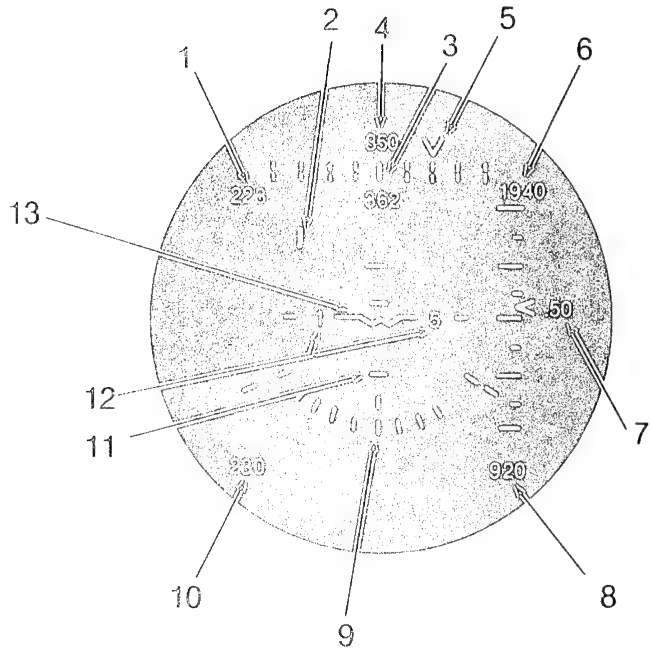
Disadvantages of Using NVG/HUD	Fixed-Wing (n)	Rotary Wing (n)
Makes Runway Acquisition Difficult	1	
Degrades Map Reading	1	
Landing Pilot has to Refocus	1	

The majority of the pilots who responded (94 percent) recommended the NVG/HUD as being useful for improving their mission performance.

PROPOSED SYMBOLS, SYMBOL MODES (OBJECTIVE 2)

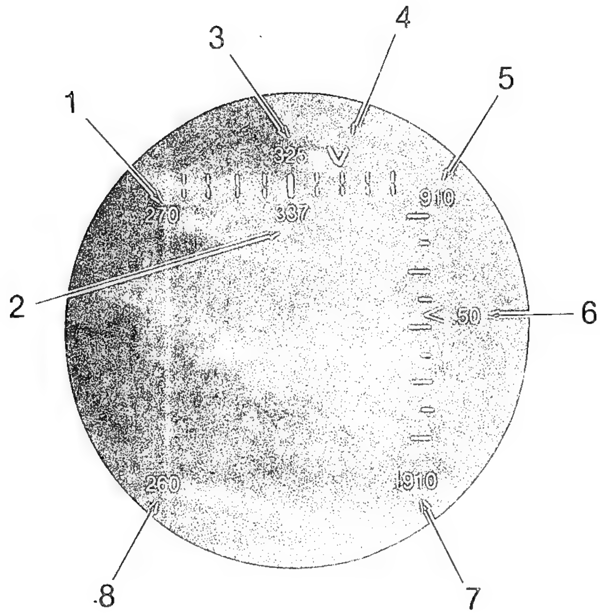
A majority of the pilots recommended expanding the HUD 14-degree instant field-of-view (IFOV) within the 40-degree IFOV of the NVG goggle. This section includes AAMRL's proposed symbols for fixed-wing and rotary-wing aircraft and includes a two-mode concept for symbol modes.

The symbols and symbol modes, shown in Figures 20 and 21, are proposed as test candidates for fixed-wing and rotary-wing aircraft. Differences in symbol scaling or movement for each aircraft are indicated in parentheses (e.g., HH-53H), where appropriate. The selections were based on pilot debriefs, questionnaire responses, and consultations with MAC personnel. Individual aircraft with unique symbol requirements were reported in summary form (Section 3) and for each pilot participant (Appendix C). Each NVG/HUD application may have to be tailored to unique signal interface and maneuvering requirements, and these data may serve as a source for selecting symbol and symbol mechanization requirements.



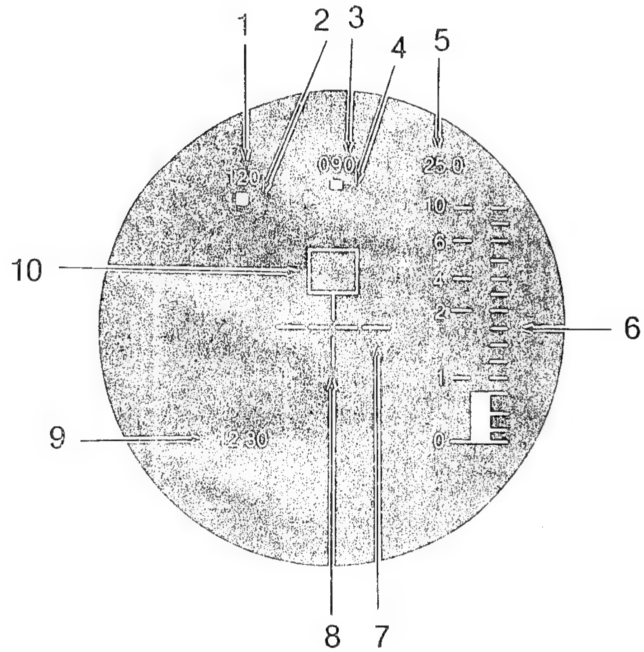
Index	Symbology	Function
1	Indicated Airspeed	Displays airspeed in 1 knot increments for full range of aircraft airspeeds.
2	Course Steering Bar	Provides left/right waypoint steering areas in relation to the course steering index. Full scale displacement is 40 degrees.
3	Magnetic Heading	Displays aircraft heading in 1-degree increments from 000 degree to 360 degrees.
4	True Track (C-141B Only)	Displays desired true track in 1-degree increments from 000 degree to 360 degrees.
5	Drift Angle	Displays left/right drift against fixed scale of 10-degree increments.
6	Barometric Altitude	Displays altitude in 10-foot increments from 0000 feet to 9990 feet.
7	Vertical Velocity	Displays velocity in 10 feet per minute increments in thousands fpm (750 fpm is displayed as .75).
8	Absolute Altitude	Displays radar in 10-foot increments at or below 300 feet and 20-foot increments above 300 feet from 000 feet to 999 feet.
9	Bank Angle	Displays 10, 20, 30, and 60 degrees of bank.
10	Ground Speed	Displays speed in 1 knot increments for full range of aircraft speeds.
11	Pitch Ladder Graduations With Artificial Horizon	Displays horizontal pitch graduations in 5-degree increments from 0 to 90 degrees.
12	Numeric Pitch	Displays pitch at 10 degrees and, thereafter, in 1 degree increments from 10 degrees to 90 degrees.
13	Aircraft Symbol	Fixed symbols.

Figure 20. Proposed Symbol Sets for Fixed-Wing Aircraft, Mode 1



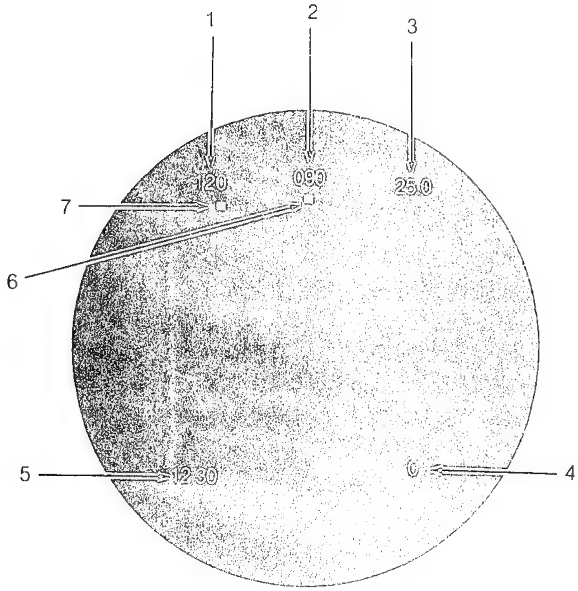
Index	Symbology	Function
1	Indicated Airspeed	Displays airspeed in 1 knot increments for full range of aircraft airspeeds.
2	Magnetic Heading	Displays aircraft heading in 1-degree increments from 000 degree to 360 degrees.
3	True Track (C-141B Only)	Displays desired true track in 1-degree increments from 000 degree to 360 degrees.
4	Drift Angle	Displays left/right drift against fixed scale of 10-degree increments.
5	Barometric Altitude	Displays altitude in 10-foot increments from 0000 feet to 9990 feet.
6	Vertical Velocity	Displays velocity in 10 feet per minute increments in thousands fpm (750 fpm is displayed as .75).
7	Barometric Altitude	Displays altitude in 10-foot increments from 0000 feet to 9990 feet. '
8	Ground Speed	Displays speed in 1 knot increments for full range of aircraft speeds.

Figure 21. Proposed Symbol Sets for Fixed-Wing Aircraft, Mode 2



Index	Symbology	Function
1	Groundspeed	Displays groundspeed in 1 knot increments.
2	Course Steering Bar	Provides left/right waypoint steering cues in relation to the course steering index. Full scale displacement is ± 20 degrees.
3	Heading	Displays aircraft heading in degrees true (HH-53H) or magnetic (UH-60A and HH-53B/C) in 1 degree increments.
4	Course Steering Index	Provides a center index for the course steering bar.
5	Distance to Next Waypoint	Displays the distance to go to the next selected waypoint in 0.1 nautical mile increments.
6	Radar Altitude Tape	Displays the radar altitude in 25 feet increments from 0 to 200 feet, 100 feet increments from 200 to 600 feet, and 200 foot increments from 600 to 1,000 feet.
7	Horizon Bar	Provides an artificial earth horizon reference.
8	Aircraft Reference	(HH-53H) Represents the aircraft flight path vector or aircraft velocity vector and is fixed at the center. (UH-60A and HH-55B/C) Represents the aircraft attitude and below 30 nautical miles-per-hour also represents the aircraft drift with respect to the box reference. The aircraft reference is fixed at the center.
9	Time to Next Waypoint	Displays the time in minutes and seconds to the next selected waypoint based on the existing groundspeed.
10	Box Reference	(HH-53H) Represents the terrain following climb/dive command or the computed local vertical. (UH-60A and HH-53B/C) Below 30 nautical miles-per-hour groundspeed the box represents a drift reference for the aircraft symbol. Above 30 nautical miles-per-hour the box disappears.

Figure 22. Proposed Symbol Sets for Rotary-Wing Aircraft, Normal Mode



Index	Symbology	Function
1	Groundspeed	Displays groundspeed in 1 knot increments.
2	Heading	Displays aircraft heading in degrees true (HH-53H) or magnetic (UH-60A and HH-53B/C) in 1 degree increments.
3	Distance to Next Waypoint	Displays the distance to go to the next selected waypoint in 0.1 nautical miles increments.
4	Radar Altitude	Displays the radar altitude in 1 foot increments from 0 to 50 feet, 5 feet increments from 50 to 100 feet, and 10 feet increments above 100 feet.
5	Time to Next Waypoint	Displays the time in minutes and seconds to the next selected waypoint based on the existing groundspeed.
6	Course Steering Index	Provides a center index for the course steering bar.
7	Course Steering Bar	Provides left/right waypoint steering cues in relation to the course steering index. Full scale displacement is ± 20 degrees.

Figure 23. Proposed Symbol Sets for Rotary-Wing Aircraft, Search Mode

Symbol Requirements for All Aircraft

Figures 24, 25, and 26 include pilot responses averaged (means) for each type of aircraft. These data are not included for design decisions which are considered to be aircraft specific but rather for research personnel examining visual information requirements for night, VFR, low altitude flight.

Figure 24 presents the adequacy of the HUD symbols for both classes of aircraft. The presentation of baro altitude, bank angle, and vertical velocity in fixed-wing aircraft and ground speed, real-time (clock time), and vertical velocity were considered marginal and in need of change of shape, movement, or deletion.

Figures 25 and 26 present pilot ratings for symbol requirements for low level, night VFR flight. For fixed-wing aircraft (Figure 25), true with mag heading and lubber line symbols for the normal mode; bank angle, true with mag heading, drift, and sky pointer symbols for the enroute mode; and baro alt and the lubber line symbols for the landing mode may not be significant requirements. For rotary-wing aircraft (Figure 26), only VVI and time to next waypoint symbols in the hover mode were rated below moderate requirement. An engineer selecting symbols for new devices might consider the symbols rated as absolute requirements as being a minimum symbol set and the priorities between moderate and absolute requirements for selecting a mode oriented set of symbols.

ADEQUACY OF DEVICE FOR LEVELS OF NIGHT ILLUMINATION (OBJECTIVE 3)

Moon disc size for the flights was estimated by the pilots to average 45 percent (range = no moon to 98 percent, n = 10) and effective ground illumination from moonlight to average 40 percent (range = 10 to 100 percent, n = 13). Visibility for all of the flights was reported as clear (unlimited) with high scattered clouds from 10 to 25,000 feet.

The majority of the pilots considered the HUD display as being adequate for all night sky illumination conditions (overcast to full moon).

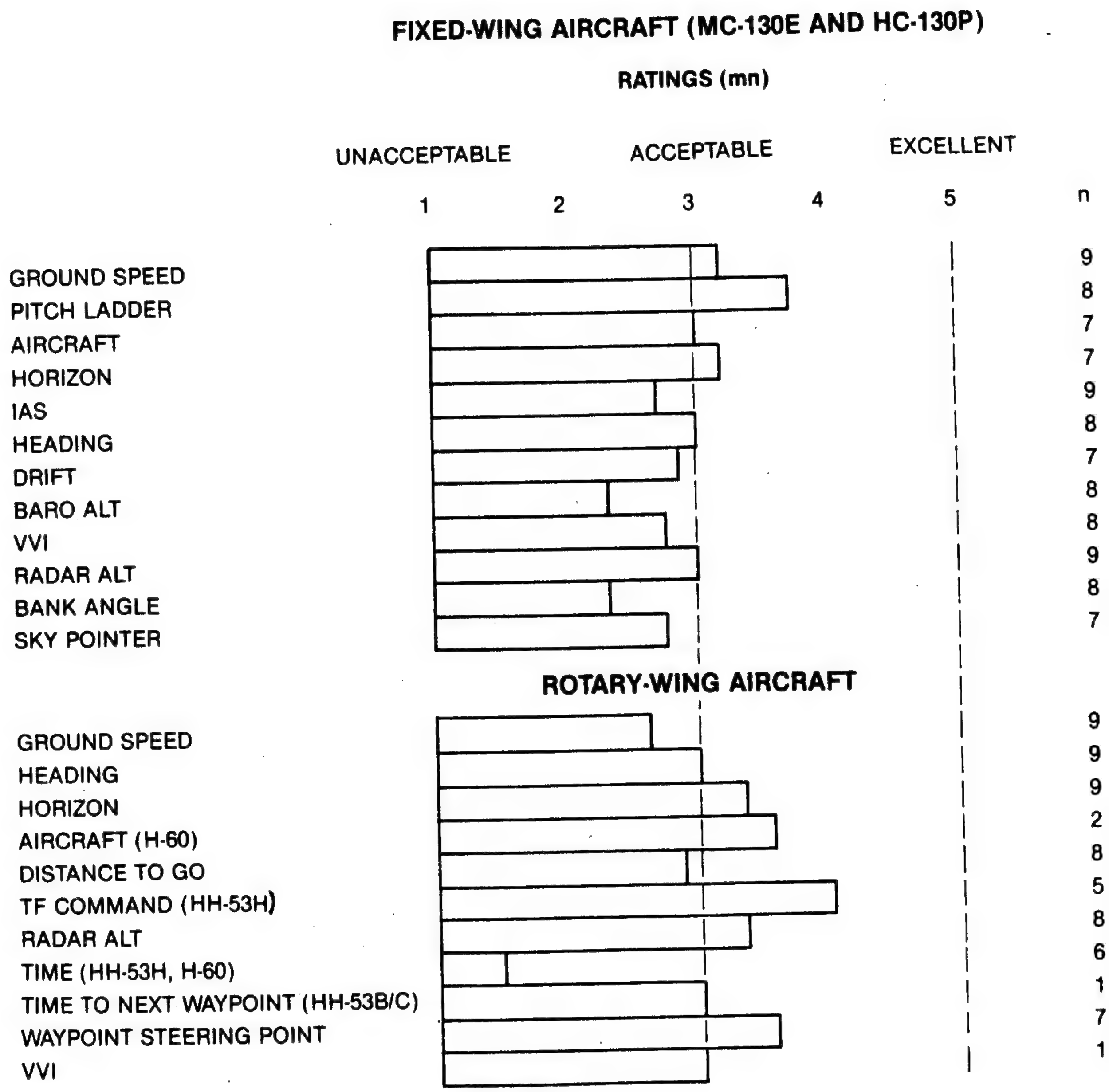


Figure 24. Adequacy of HUD Symbols

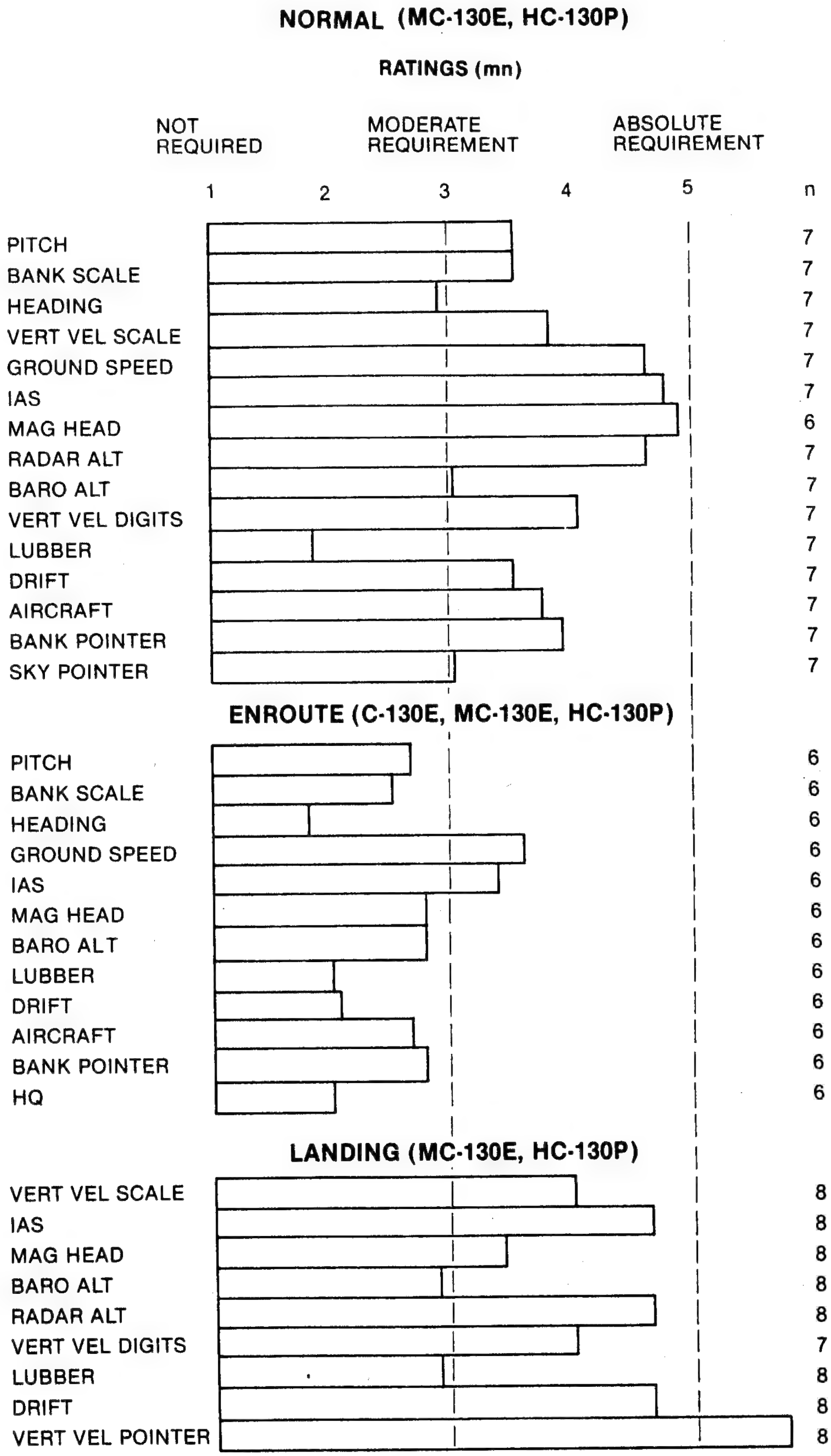


Figure 25. Symbol Requirements for Fixed-Wing Aircraft

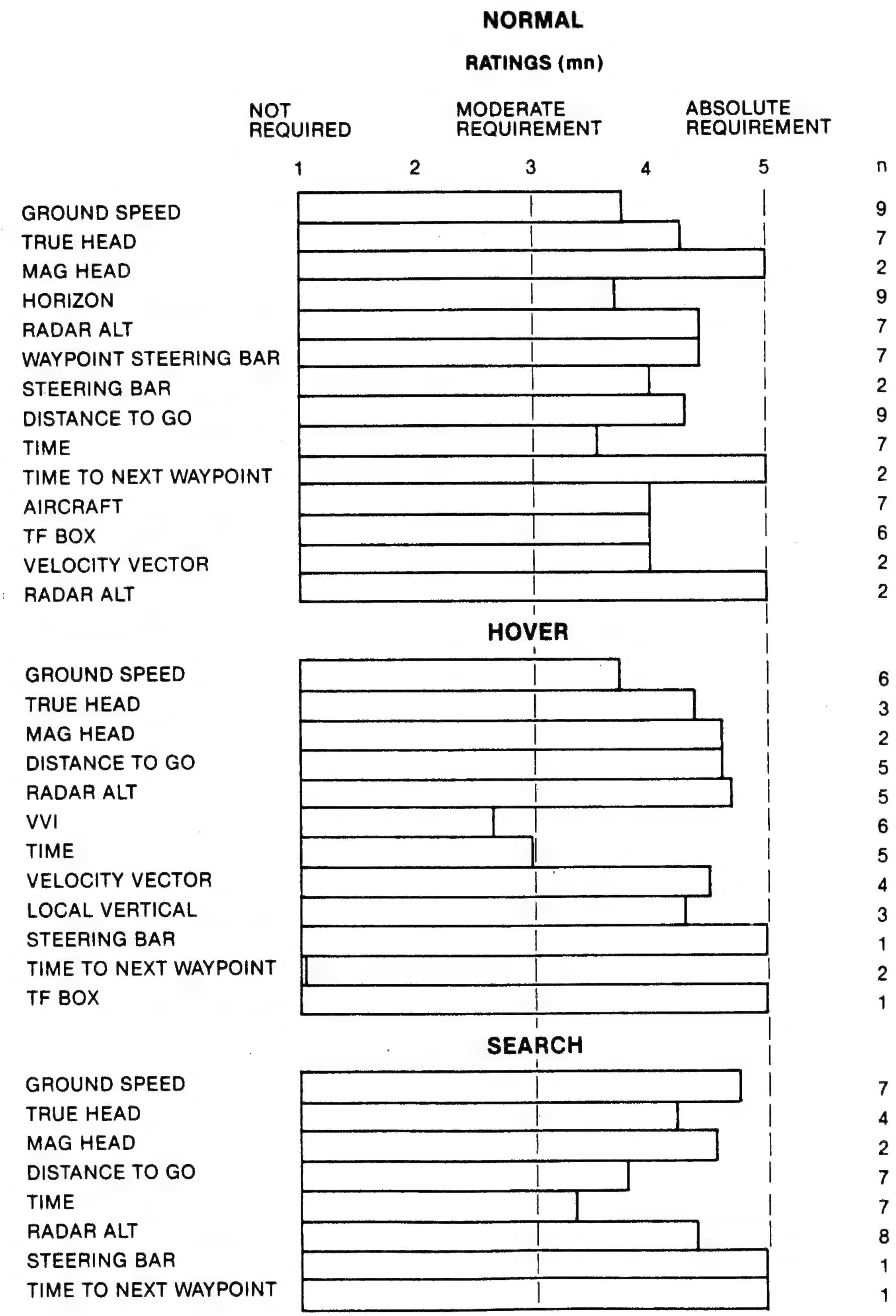


Figure 26. Symbol Requirements for Rotary-Wing Aircraft

CONTROL REQUIREMENTS (OBJECTIVE 4)

The five controls shown in Figure 6 (for power, pitch adjust, mode select, barometric adjust, and brightness adjust (on the helmet) are proposed for an NVG/HUD specification. On a vertically aligned panel, the mode button was recommended for the top position (unless the panel is overhead) and for the nearest position to the pilot for horizontally aligned buttons. Individual pilots recommended the mode button be installed on the cyclic, run the optic cable on top of the helmet, and add a control for symbol intensity. All of the eight rotary-wing pilots said that operation of the NVG/HUD controls did not interfere with any other equipment nor did the operation of other equipment interfere with operation of the NVG/HUD. The optic bundles might impede movement in the cockpit in an emergency.

COMPATIBILITY WITH CURRENT EQUIPMENT (OBJECTIVE 5)

A microprocessor based data collection and formatting unit was developed to provide interfaces to all of the required sensor data. Signals were scaled and formatted to an ARINC 429 standard for transmission to a symbol generator. Software was prepared using assembly language for each aircraft. Generally, pitch and roll signals were derived from attitude gyros; heading from a directional gyro; radar altitude from a radar altimeter; navigation data from a doppler radar; and attitude, airspeed, and vertical velocity from pitot-static systems. Installation downtimes were minimized by the introduction of a common data collection and formatting unit.

OPERATIONAL PROCEDURES (OBJECTIVE 6)

The fixed-wing pilots commented on the probable elimination of communication from the copilot and radar navigator to the pilot (especially concerning airspeed and altitude) (MC-130E); both pilots could simultaneously use goggles on the entire mission (HC-130P) and its use would promote more aggressive flying (HC-130P). The rotary-wing pilots also commented on the reduction of communication requirements, the reduction of light in the cockpit by turning off the bright FLIR display, and its aid as an instructors' device; however, crew coordination would have to be increased for

Night Recover System (NRS) equipped aircraft that requires the flight engineer to operate a camera. Formal checklist requirements for tuning and checking the device and copilot calls to the pilot to change modes ("before takeoff, before landing") were recommended.

TRAINING REQUIREMENTS (OBJECTIVE 7)

Table 6 summarizes pilot recommendations for training requirements (one to three flights) for NVG qualified pilots.

TABLE 6. TRAINING REQUIREMENTS

Aircraft	Pilot Comments	n
MC-130E	One ride (one low approach or until comfortable, one flight of 2 hours).	3
	Two rides (minimum of four landings and one go-around each ride).	1
HC-130P	No special requirement.	1
	Two rides (with an IP).	1
Rotary	One ride [2-hour sortie after a training session, include a new sortie with approaches and hovering over a landing zone (LZ)].	2
	One to two rides (include terminal operations, low level formation, terrain masking, and refueling).	2
	Two to three rides.	2

NVG/HUD APPLICATION CONSIDERATIONS

The impetus for the use of night vision optics started with the use of hand-held starlight scopes with the U.S. Army ground and air forces in Vietnam. The Air Force soon adopted handheld and gimballed TV and IR devices in a variety of recon and strike aircraft. The astonishing success of side-firing aircraft in Vietnam (Ballard, 1982) and later in Grenada, confirms the necessity for having a night VFR target detection and strike capability. The requirement for penetrating a high threat, night, Warsaw Pact conflict with low level tactics has been well documented and will doubtless proliferate the use of night optics into future systems.

Future developers should consider the NVG factors listed in Table 7 as the three services move into airborne low level night operations.

TABLE 7. NVG/HUD APPLICATION CONSIDERATIONS

Factors	Comments
Field of View	Restrictions of FOV (40 degrees for Generation III NVG) may affect scanning patterns and target acquisition capabilities. Any restriction of the aft or high scan envelope may directly affect formation, refueling, or air combat maneuvers.
Visual Fatigue	Anticipate visual fatigue problems because of the monocular presentation and close focused symbols superimposed over an image at infinity. Some pilots may reduce cross checks and tend to focus on the close symbols.
Helmet Weight	Physiological fatigue for some pilots is increased with increased helmet weight and type of weight distribution.
Optics Bundles	The bundles may limit head movements and body movements.

Appendix A

NVG/HUD DEMONSTRATION DEVICE

This appendix briefly describes the following components of the demonstration device used in this study:

A block diagram of the entire system is shown in Figure 27. The flight instrument raw signal information was collected by the aircraft's signal processing computer and converted into ARINC 429 formatted data. These data were transmitted across the ARINC bus to a CRT display. The display converted the data to white symbols on a black background. The symbols were reflected from a front surface mirror to a relay lens which focused the image onto a flexible fiber optic bundle. The bundle carried the image to the NVG where a collimating lens moved the image to optical infinity. This image was then reflected from a beam splitter into the NVGs. The observer saw the image of the symbols superimposed over the outside view. The NVG/HUD wiring diagram is shown in Figure 28.

DISPLAY

A Hewlett Packard (HP) monitor was selected for a symbol display because of its high resolution and quality of text and graphics. The specifications for the HP 6-inch CRT (Model 1345A) that relate to symbol and picture quality are listed in Table 8.

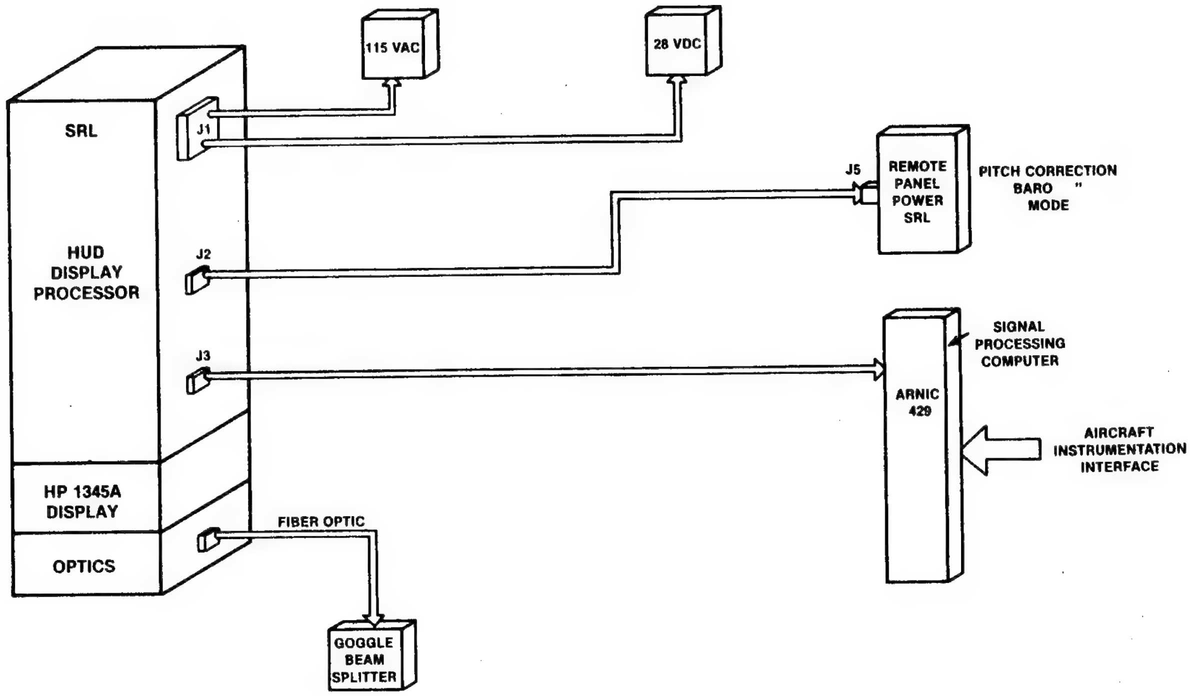


Figure 27. NVG/HUD Block Diagram

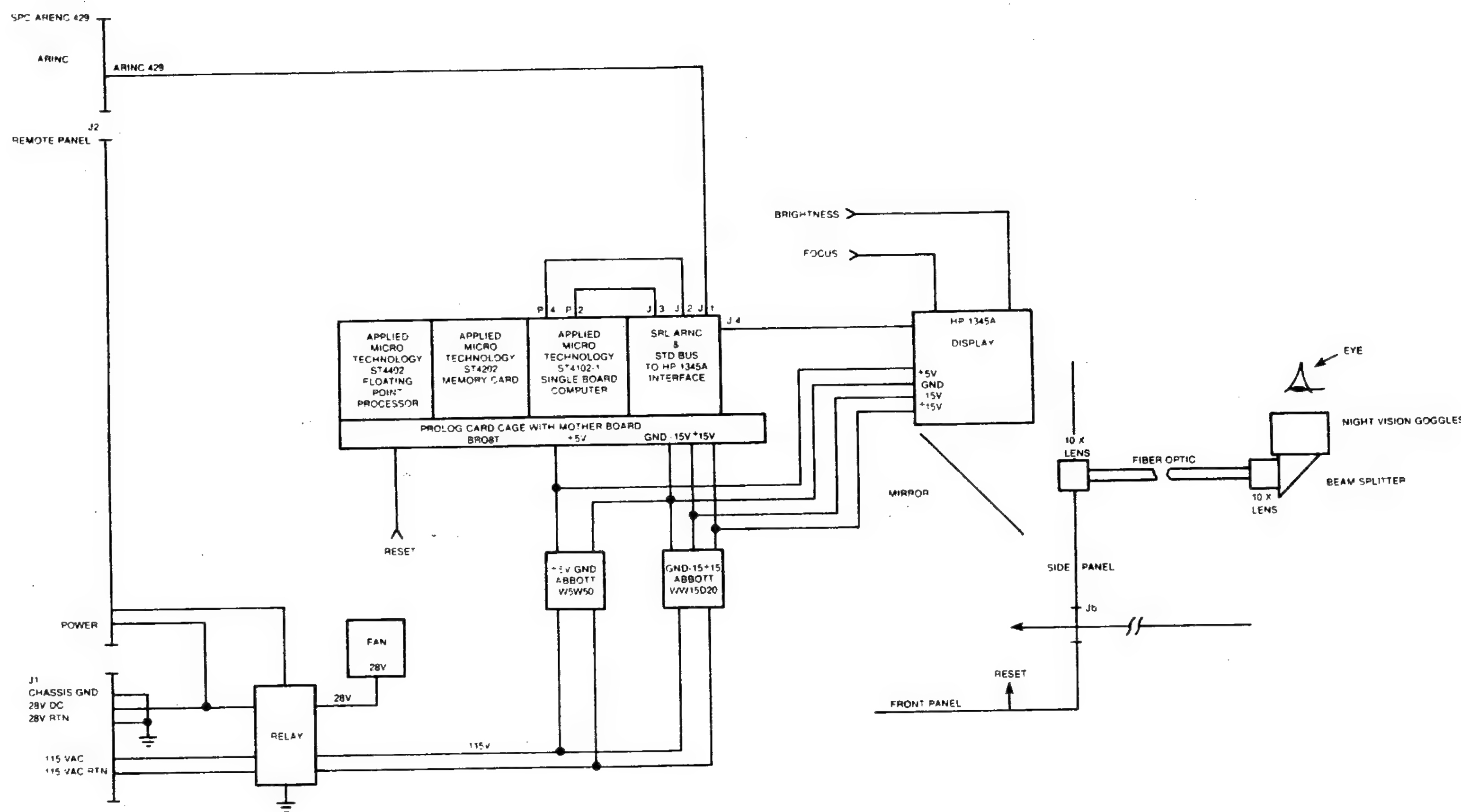


Figure 28. NVG/HUD Wiring Schematic

TABLE 8. DISPLAY SPECIFICATIONS

DIGITAL INPUT INTERFACE **SIGNAL LINES** **Data Acceptance Rate**: Controlled by 1345A, user processor, and vector length. From approximately 10K words/second to 667K words/second. **VECTOR GENERATOR** **Random Vector Plotting**: Addressable resolution 2048 x 2048 points. PROGRAMMABLE DELTA-X INCREMENT FOR GRAPHING. **3 Programmable Intensities**: Dim, half brightness, full brightness (PLUS BLANK OR OFF). **4 Programmable Line Types**: Solid line, solid line with intensified endpoints, short dashes, long dashes. **4 Programmable Writing Speeds**: Approximately 1.3, 2.5, 3.8, and 5.1 mm per microseonds. VECTOR DRAWING TIME = 1 microsecond per vector + (Length of Vector divided by Writing Speed). **CHARACTER GENERATOR** Stroke characters--36 x 24 point resolution; modified full ASCII set. Character strokes are stored in ROM. Average character writing time is 16 microseconds, including processing time. **4 Programmable Character Sizes**: 1X = 56 characters per line, 29 horizontal lines possible. 1.5X = 37 characters per line, 19 horizontal lines possible. 2X = 28 characters per line, 14 horizontal lines possible. 2.5X = 22 characters per line, 11 horizontal lines possible. **4 Programmable Character Orientations**: 0, 90, 180, and 270 degrees (ccw) relative to horizontal. **CATHODE-RAY TUBE** **Type**: Electrostatic focus and deflection, post accelerated. Aluminized P31 phosphor **Screen Size**: 16 cm diagonal **View Area**: 119 cm^2, 9.5 cm vertically by 12.5 cm horizontally. **Brightness**: $\geq$ 169 Cdm^2 at 1.3 mm/microsecond writing rate, full brightness at 60 Hz refresh rate. **Bezel**: Compatible with HP 197A/B camera equipped with 10375A adapter (order 197B Option 006) fits most HP small screen displays and Tektronix 6900, 5100, and 7000 series instrument.

SYSTEM CONNECTIONS

The display unit used 115V AC, 400 Hz for main power and 28V for a cooling fan and remote panel power-up relay. The unit and signal processing computer used a commercial two-wire bus (ARINC 429) that was a component in the C-141B FSAS system. The same bus was used for other aircraft.

DISPLAY PROCESSOR

The processor included a 280 single board computer system, floating point match card, 32K memory band with a 12K EPROM system program, and an interface card for the HP 1345A display and ARINC 429 bus.

OPTICS

The optical components included a front surfaced mirror, two 10X microscope objective lenses, fiber optic bundles, and a beam splitter. The CRT image was reflected on the front surfaced mirror as a focusing line. A lens focused the image on the fiber optic bundles which was transmitted to the pilot's helmet. Another lens focused this image on the beam splitter.

AIRCRAFT INSTRUMENTATION INTERFACE

The aircraft interfaces were many and varied in their signal types and specifications and required interfaces to various sensors such as gyroscopes, doppler navigation systems, inertial navigation systems, radar and barometric altimeters, etc. A microprocessor based data collection and formatting unit was designed and fabricated to provide interfaces to all required sensor data. The data collection unit provided the input capabilities listed in Table 9. The signals were scaled and formatted to an ARINC 429 standard for transmission to a symbol generator. Software was prepared using assembly language for each aircraft installation. The 8085 microprocessor contained 16K of RAM and 16K of PROM available on the processor card. The program size for each installation was approximately 4K bytes.

In general, roll and pitch signals were derived from attitude gyros as synchro sources. The heading data were taken from the directional gyro. Barometric data (altitude, airspeed, vertical velocity) was taken from a pitot-static transducer, and the additional navigation data from a doppler navigation radar. The radar altimeter was used for sensing altitude above the ground.

TABLE 9. DATA COLLECTION UNIT INPUT SIGNALS

Signal Type	Number of Channels	Signal Description
Synchro	8	11.8 VRMS, 400 Hz 3 Wire Angle Data
DC	9	±1 to ±50 VDC >100K input impedance
Discrete	12	Switch closures to ground or 28 VDC
ARINC 575	1	2 wire digital biphase data 32 bit word length 10 kHz data rate
ARINC 561	1	2 wire data 2 wire sync 2 wire clock 32 bit word length 10 kHz data rate

PILOT CONTROLS

For the first aircraft, the C-141B, the pilot was given power, focus, and brightness controls on a cockpit panel. For the next aircraft, the focus control was eliminated and the brightness control was moved to the pilot's helmet. Barometric correction, pitch correction, and mode switching controls were added to a cockpit panel (see Figure 6).

NIGHT VISION GOGGLES

The following description of Generation II (Gen II) NVGs and Figure 29 was abstracted from Helicopter Night Flying (see references). The Generation III NVGs used in this study were helmet rather than head-mounted and provided increased viewing performance.

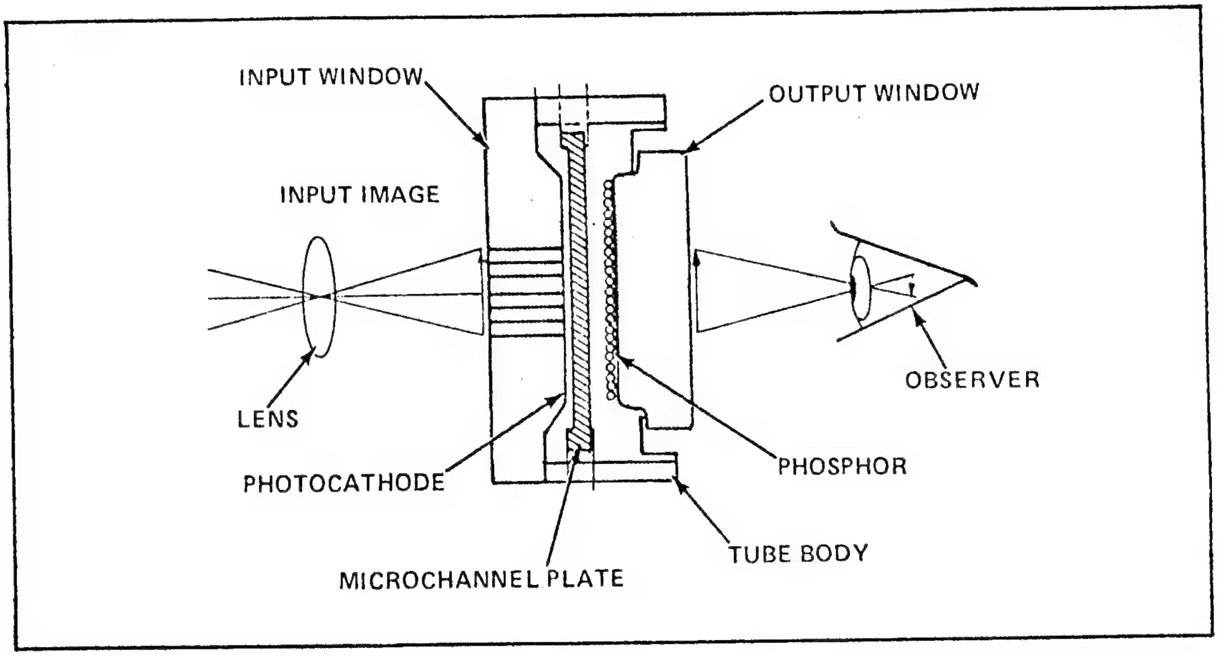


Figure 29. Image Intensifier Tube Construction (from Helicopter Night Flying)

The Gen II NVGs have an FOV of 40 degrees, weigh 1.9 pounds, and operate from a self-contained 2.7 v mercury battery.

These goggles amplify ambient and near IR light to provide an electronic display for each eye of the wearer. Light levels as low as 1/10,000 ft candles yield sufficient light energy for viewing. This is equivalent to bright starlight conditions. The ideal light level for sharpest resolution is a quarter moon. Any additional light above this level is adjusted by the automatic-brightness-control (ABC) circuitry in the goggles to prevent "blooming" or washing-out of the image. Light levels below the minimum result in loss of resolution or sharpness of the image. However, supplemental IR or other artificial lighting may be used to enhance the image within the range of light source.

In the center of each goggle tube is an image intensifier tube. It has three basic elements: (1) a photocathode for conversion of photons to electrons, (2) a micro channel plate for electron multiplication, and (3) a phosphor coating for conversion of electron energy back to photons. The input window is actually a bundle of fiber-optics ground into a lens and constructed with a 180-degree twist to yield a "right-side-up" image for viewing. The fiber-optics are drawn sufficiently small so as to provide point sources of light energy (photons) in a large enough quantity to build a picture or image. Since

each fiber passes one element of the image, the entire image is a mosaic.

The photocathode, which is electrically charged, is a thin coating on the inside of the first fiber optic. The microchannel plate, which has voltage applied across the surfaces, consists of a bundle of about one-million hollow fibers. Electrons emitted from the photocathode pass through the microchannel plate hollow fibers--impacting on the walls and picking up additional energy, as well as liberating secondary electrons. These electrons, now increased in number and energy, impinge on the surface phosphor coating of the last fiber optic lens. This phosphor glows like a TV picture tube.

A power supply module is wrapped around each image intensifier tube to provide an oscillator circuit and the necessary voltage multiplication to operate the tube. In addition, both the front and rear of the tubes are fitted with optical lenses to permit light gathering and focusing capabilities.

The entire goggle assembly has several adjustments for comfort and individual physiological differences. Each eyepiece lens can be adjusted from +2 to -6 diopters to correct for visual acuity; the front of each tube has an adjustment on the objective lens for focusing from 10 in to infinity; both tubes can be adjusted for horizontal spacing for interpupillary variances; and the entire lens assembly can be tilted up or down and projected away or towards the eyes by means of clamps on each side of the shell.

Appendix B
PILOT QUESTIONNAIRES

This appendix includes the following questionnaires written by MAC and AAMRL for debriefing the pilots on the usefulness of the NVG/HUD system for low level operations.

The general questionnaire remained unchanged for all of the tests, whereas the aircraft questionnaire was slightly modified with changes in symbol sets and control options for each aircraft. The questionnaire for the C-130E has been included as a representative example of the fixed-wing questionnaires and the HH-53B/C questionnaire as an example of the rotary-wing questionnaires.

GENERAL QUESTIONNAIRE

NAME: ______________________________ TOTAL FLYING HOURS: __________________

CREW POSITION: __________________ SOLL II FLYING HOURS: ________________

DATE: ______________________________ NUMBER OF MONTHS SOLL II QUALIFIED: ___

1. DID THE NVG HUD PROVIDE USEFUL INFORMATION? YES ____ NO ____ IF NO, EXPLAIN. ____

____

____

____

2. WAS ANY PHASE OF THE MISSION DEGRADED BY USE OF THE NVG HUD? YES ____ NO ____ IF YES, EXPLAIN. ____

____

____

____

3. IDENTIFY BY PHASE OF FLIGHT WHAT INFORMATION IS IMPORTANT, WHAT YOU WANT DISPLAYED AND HOW YOU USE THAT DISPLAY.

A. EN ROUTE: ____

____

____

____

B. APPROACH AND LANDING: ____

____

____

____

C. GROUND OPERATIONS: ____

____

____

____

D. TAKEOFF AND CLIMBOUT: ____

____

____

____

4. BASED ON YOUR RESPONSE TO QUESTION 3, HOW SHOULD NVG HUD INFORMATION BE DISPLAYED? (USE THE DIAGRAM PROVIDED) ____

____

____

____

5. WHAT IS THE MINIMUM TRAINING REQUIRED TO SAFELY AND EFFECTIVELY USE THE NVG HUD? ____

____

6. EVALUATE THE COCKPIT CONFIGURATION AND THE PHYSICAL LOCATION OF NVG HUD EQUIPMENT. ____

____

____

7. WERE THERE PHYSIOLOGICAL FACTORS THAT AFFECTED YOUR USE OF THE NVG HUD? YES ____ NO ____ IF YES, EXPLAIN. ____________________________________

____

____

8. COMPARE THE PRESENTATION OF NVG HUD INFORMATION ON THE PVS-5 AND AN/AVS-6 NVG. ____

____

____

____

9. COULD THE NVG HUD ENHANCE THE SOLL II MISSION? YES ____ NO ____ EXPLAIN.

____

____

____

10. COMMENTS BY OTHER CREW MEMBERS. IDENTIFY BY CREW POSITION. ___________

____

____

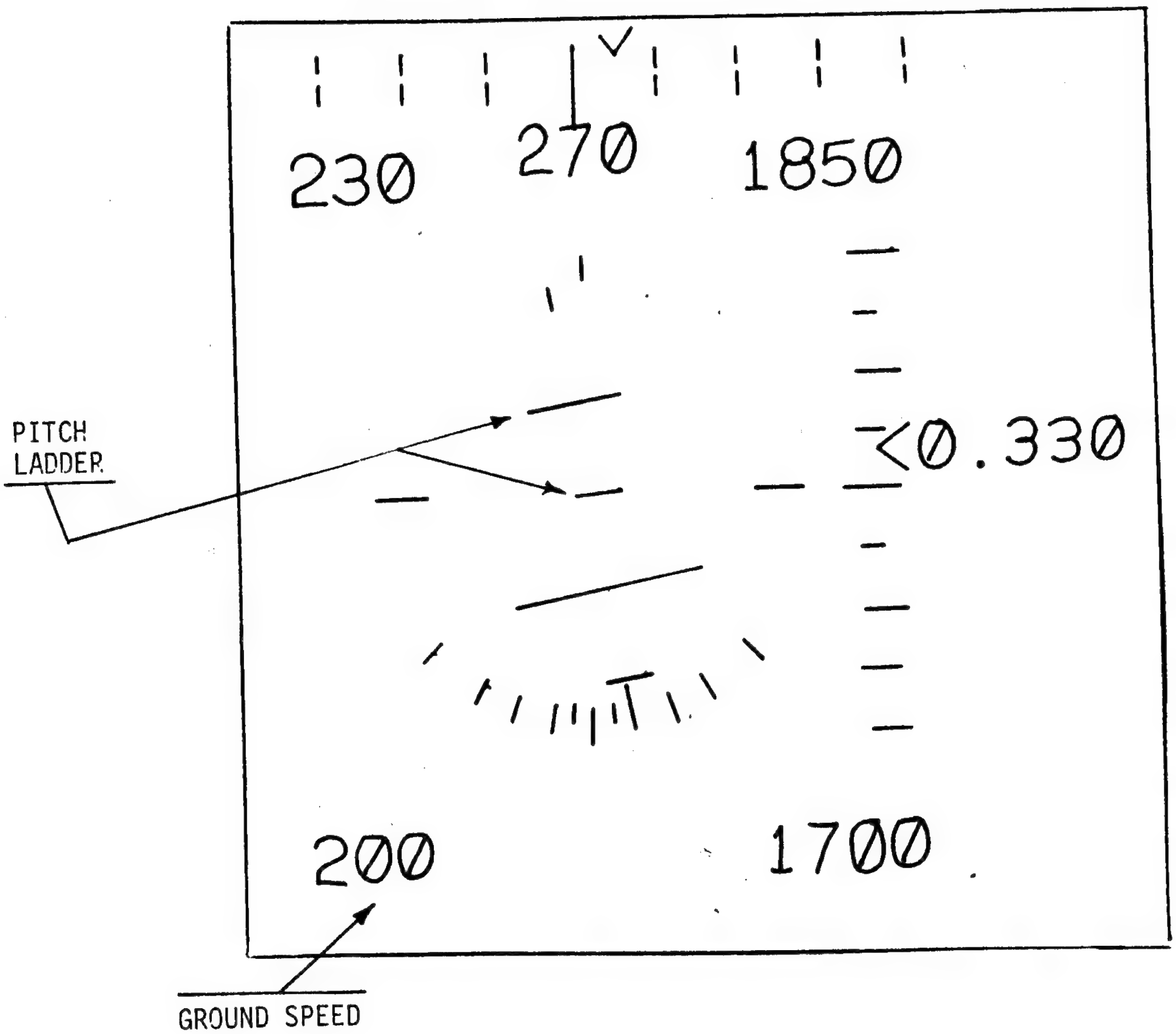
____

____

C-130E/AWADS QUESTIONNAIRE

This questionnaire will be used to gain immediate feedback about the NVG/HUD used in your aircraft special operations. Please rate the adequacy of the SYMBOLS and cockpit CONTROLS for a real night VFR mission.

Please follow the directions for each section of the questionnaire.


230
270
1850
PITCH
LADDER
<0.330
200
1700
GROUND SPEED

ADEQUACY OF SYMBOLS

Using the diagram of the NVG/HUD (opposite page) as a guide, please rate each symbol by circling the number that corresponds to your impression of the presentation of the SYMBOL for flying night VFR operations and, if desired, state the reason for changing the symbol.

The **GROUND SPEED** symbol is:

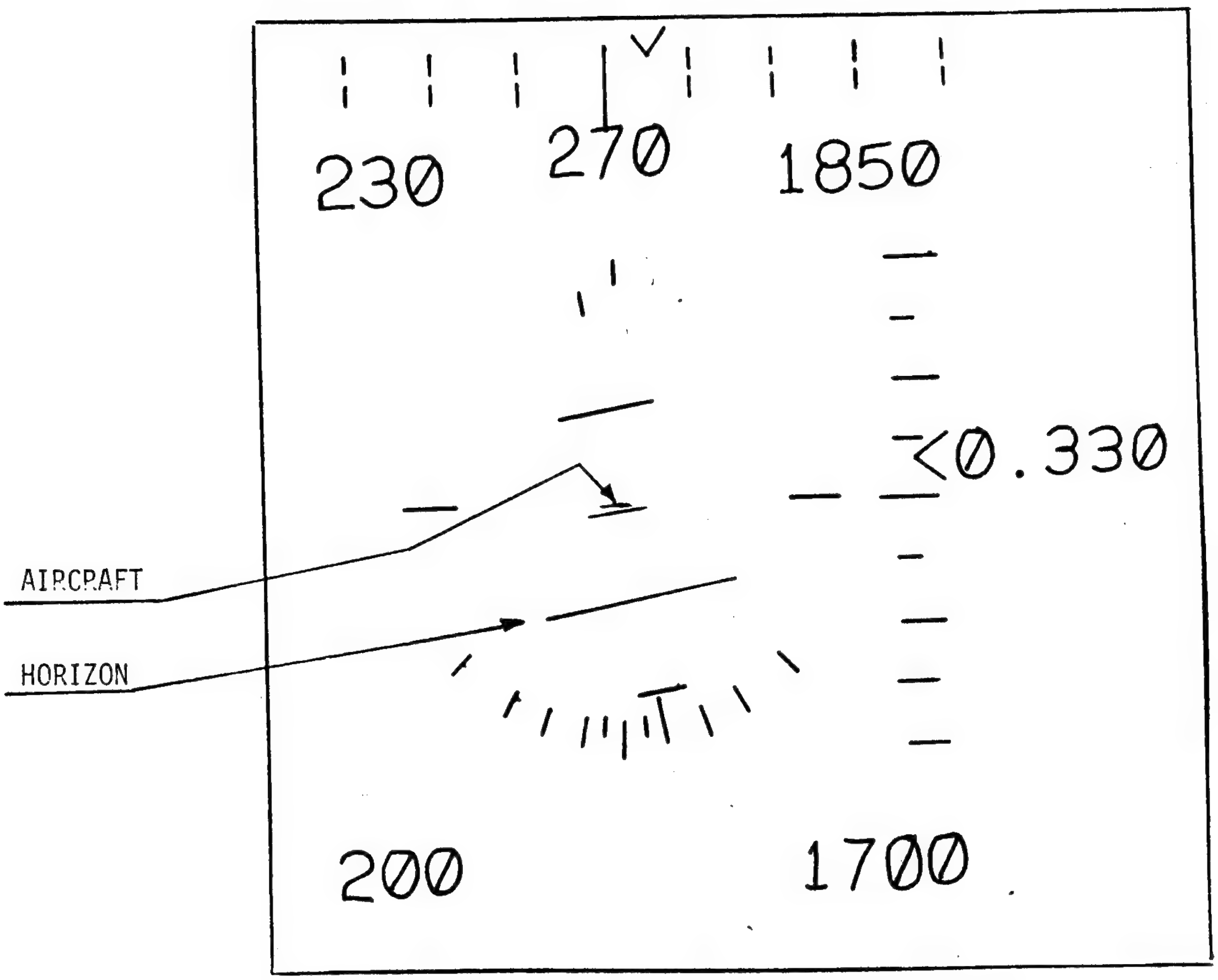
1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Size?			
Location?			
Movement?			
Add a scale?			
Delete?			

The **PITCH LADDER** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

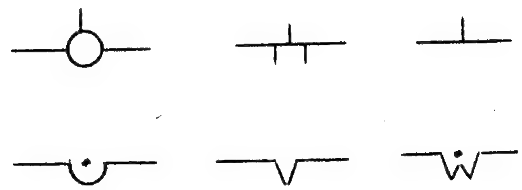
Would you change its:	YES	NO	COMMENTS
Interval?			
Length of step?			
No. of steps?			
Label steps?			
Add above/below horizon cues?			


230
270
1850
<0.330
AIRCRAFT
HORIZON
200
1700

The center of the **AIRCRAFT** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its shape?
(circle preference)

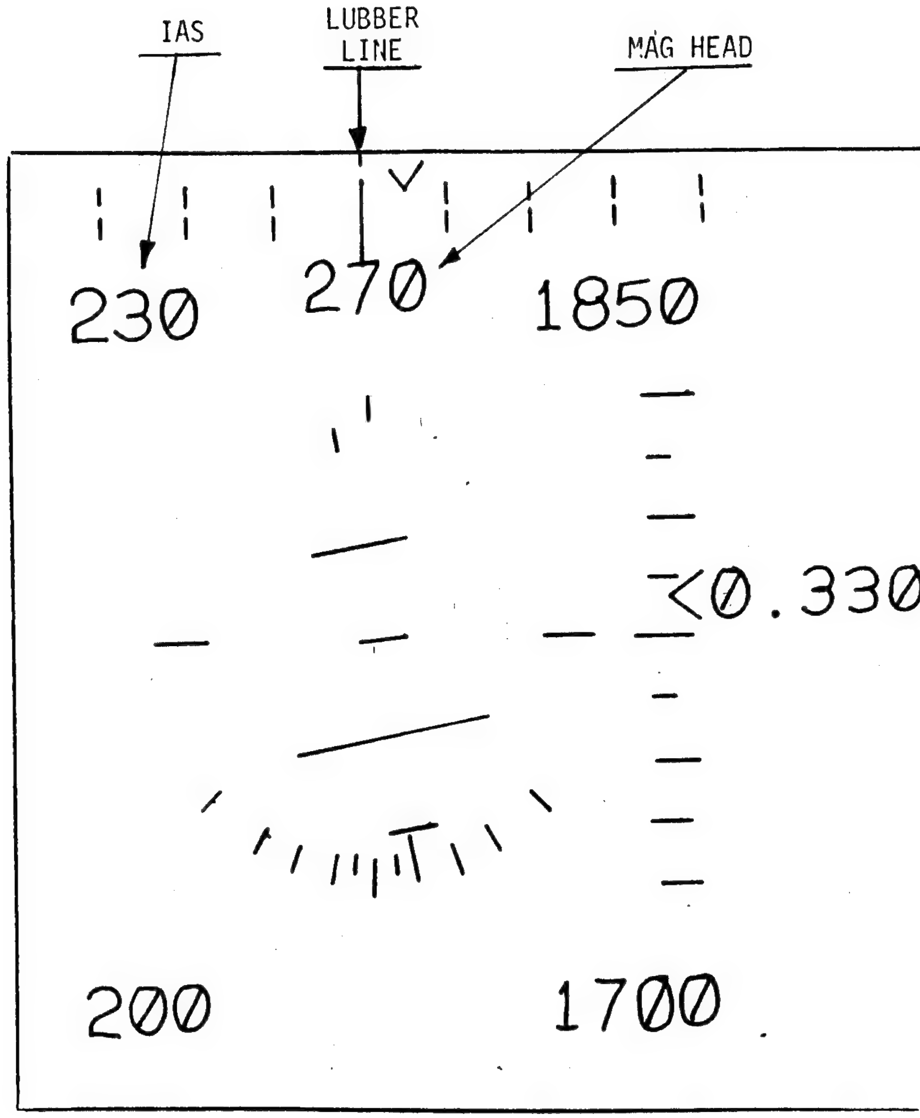


Comments?

The **HORIZON** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Width?			
Rate of movement?			


IAS
LUBBER LINE
MAG HEAD
230
270
1850
<0.330
200
1700

The $\boxed{\textbf{IAS}}$ symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

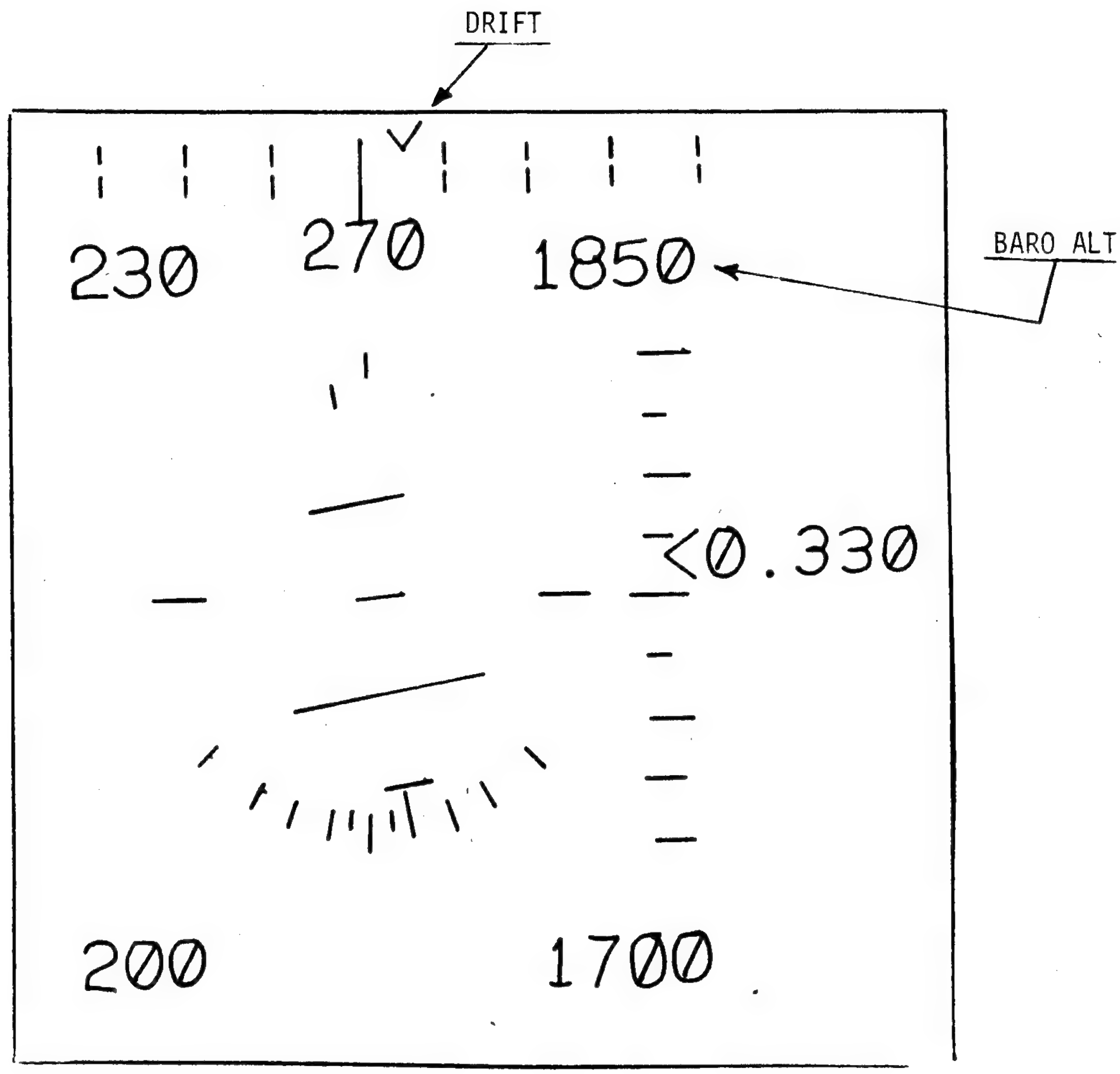
	YES	NO	COMMENTS
Size?			
Location?			
Add a scale?			
Movement?			
Add a label?			
Delete?			

The $\boxed{\textbf{MAG HEAD}}$ symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Location?			
Scale Movement?			
Delete?			
Delete the scale or lubber line?			
Add a label?			



DRIFT
BARO ALT
230
270
1850
<0.330
200
1700

The $\boxed{\textbf{DRIFT}}$ symbol is:

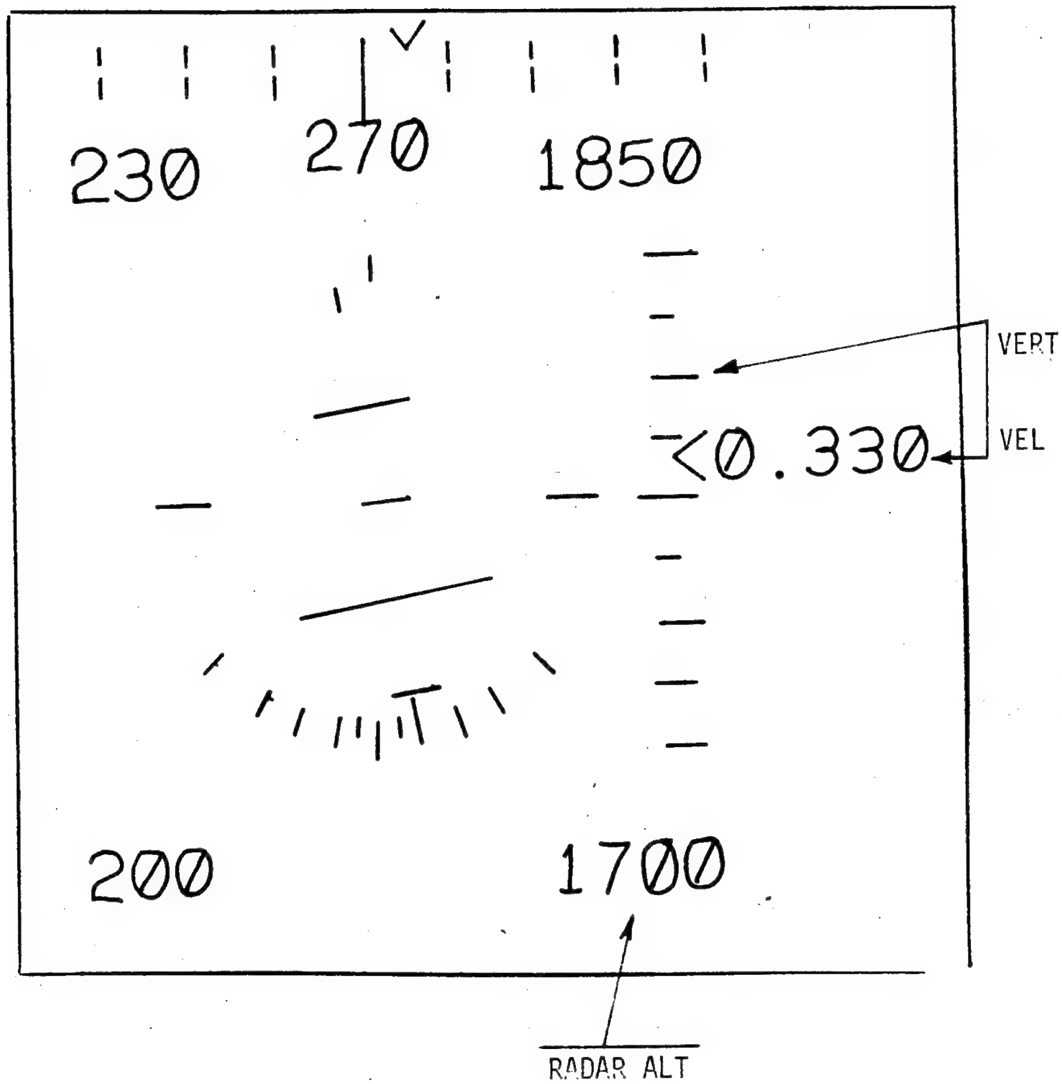
1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Shape?			
Size?			
Scale?			
Movement?			
Delete?			

The $\boxed{\textbf{BARO ALT}}$ symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Size?			
Location?			
Movement?			
Add a scale?			
Add a label?			
Delete?			


230
270
1850
VERT
VEL
<0.330
200
1700
RADAR ALT

The **VERT VEL** symbols are

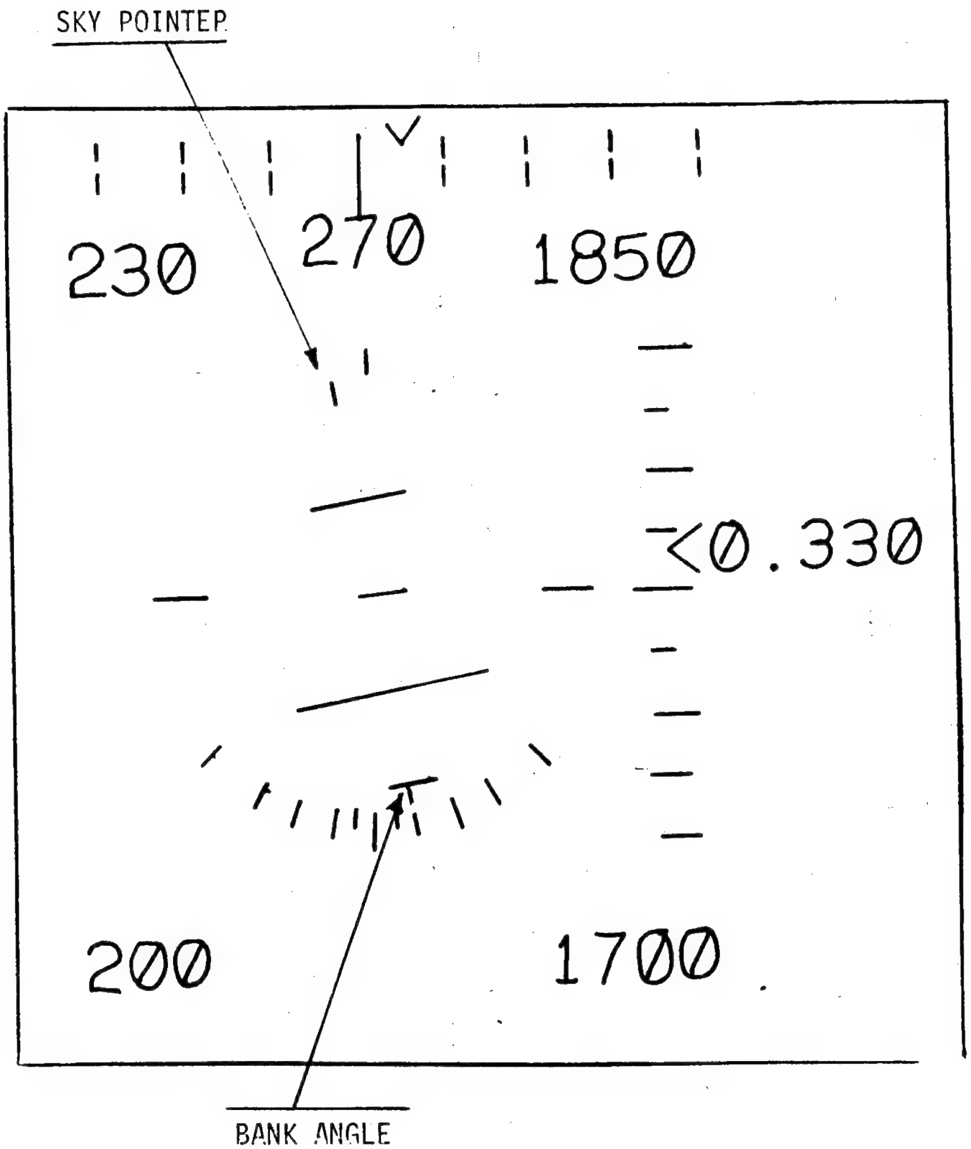
1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Scale?			
Pointer?			
Digital size?			
Location?			
Movement of digits?			
Movement of pointer scale?			
Delete decimal?			
Delete leading Ø?			

The **RADAR ALT** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Size?			
Location?			
Add a scale?			
Movement?			
Add a label?			
Delete?			


SKY POINTER
230
270
1850
<0.330
200
1700
BANK ANGLE

The **BANK ANGLE** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

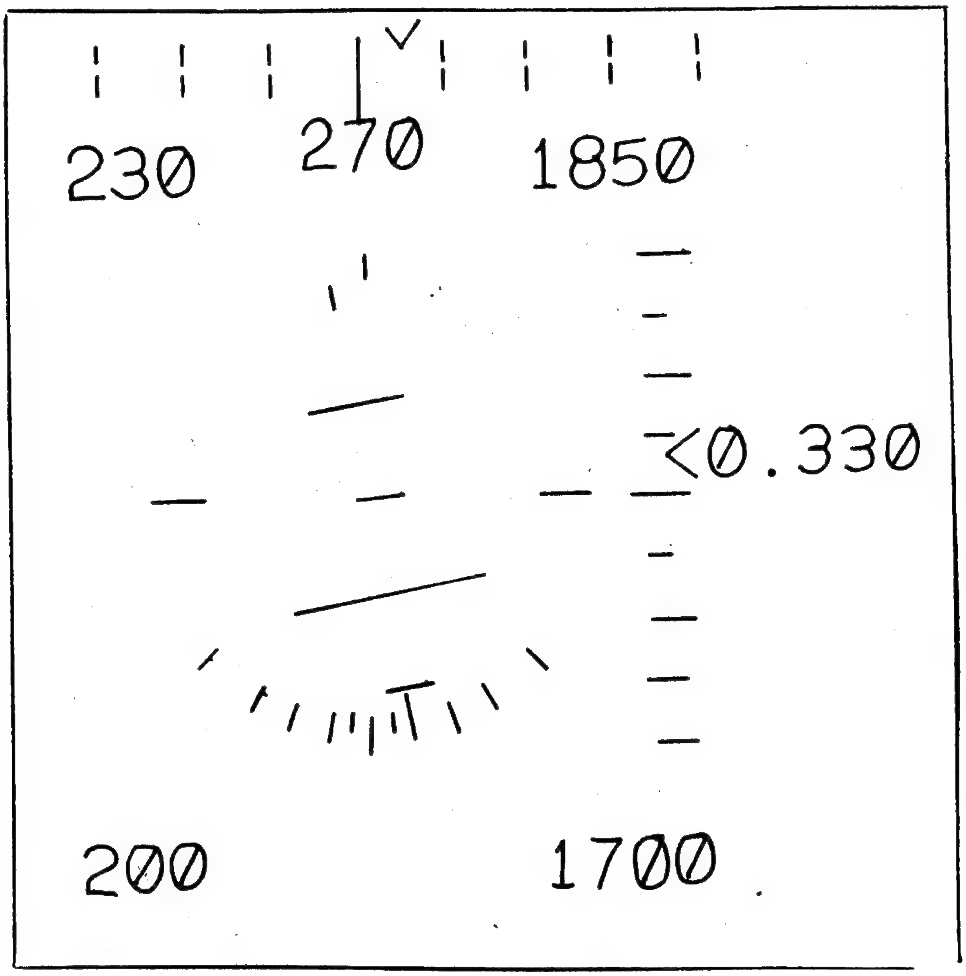
Would you change its:	YES	NO	COMMENTS
Shape?			
Size?			
Scale?			
Rate of movement?			
Add a label?			
Delete?			

The **SKY POINTER** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Shape?			
Size?			
Scale?			
Rate of Movement?			
Delete?			

STANDARD MODE



ADEQUACY OF MODES

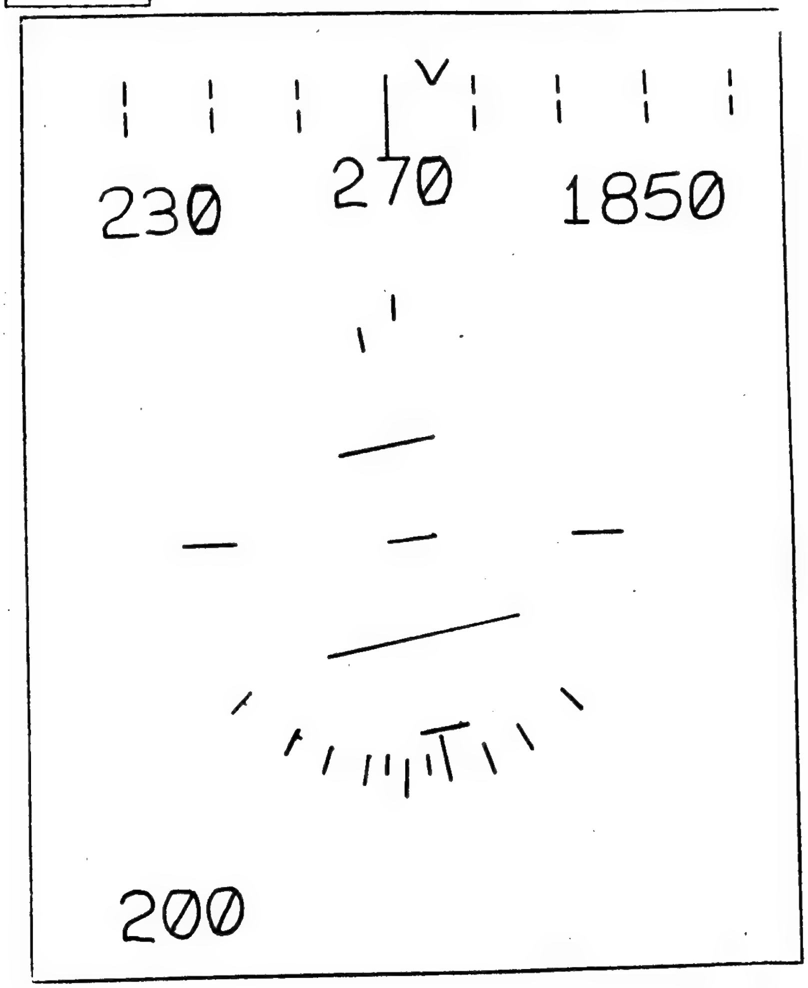
Now that you have rated each symbol, we would like your ideas on the symbol sets for the 3 operating modes.

Using the **STANDARD** mode shown on the opposite page, please rate the need for each symbol.

1	2	3	4	5
Not Required		Moderate Requirement		Absolute Requirement

	Insert Number From Scale Above	Please Comment On Any Rating from 1 to 3
(4 scales)		
pitch		
bank		
heading		
V/V		
(6 number groups)		
GS		
IAS		
MAG HEAD		
RADAR ALT		
BARO ALT		
V/V		
(5 pointers)		
lubber		
drift		
aircraft		
bank		
sky		

ENROUTE MODE

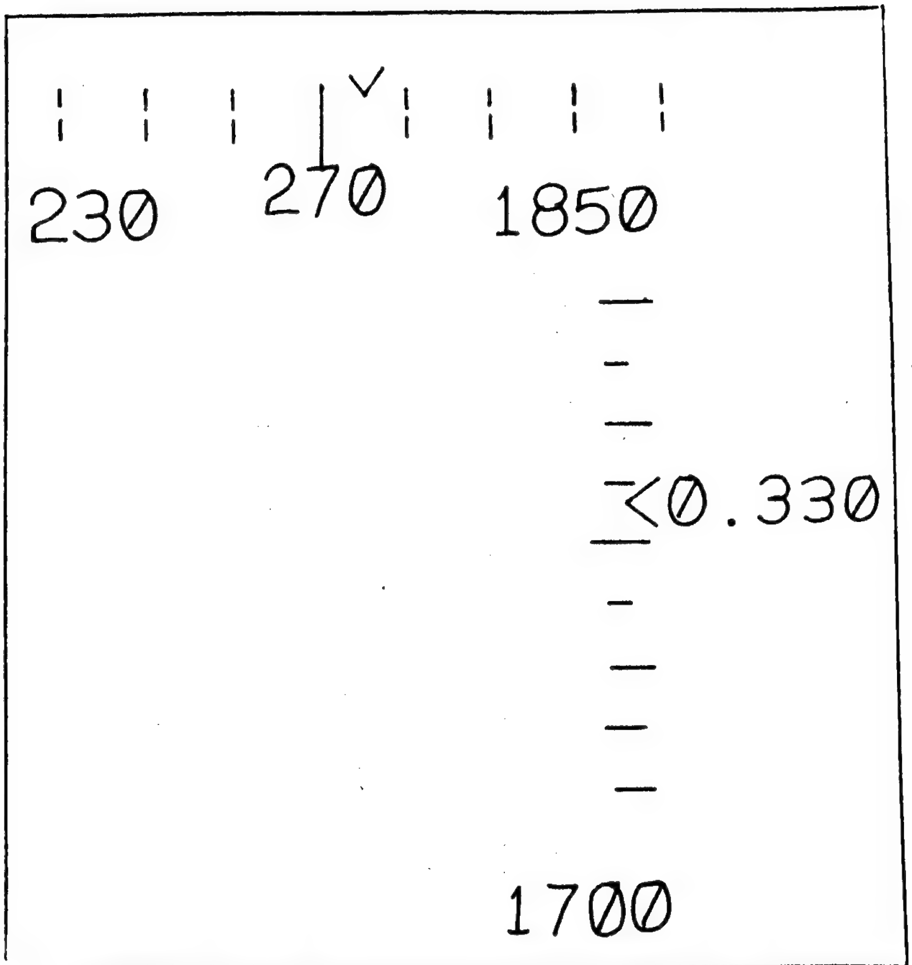


Using the $\boxed{\textbf{ENROUTE}}$ mode shown on the opposite page, please indicate your requirements for each symbol.

1	2	3	4	5
Not Required		Moderate Requirement		Absolute Requirement

	Insert Number From Scale Above	Please Comment On Any Rating from 1 to 3
(3 scales)		
pitch		
bank		
heading		
(4 number groups)		
GS		
IAS		
MAG HDG		
BARO ALT		
(5 pointers)		
lubber		
drift		
aircraft		
bank		
sky		

LANDING MODE



Using the **LANDING** mode shown on the opposite page, please indicate your requirements for each symbol.

1	2	3	4	5
Not Required		Moderate Requirement		Absolute Requirement

	Insert Number From Scale Above	Please Comment On Any Rating from 1 to 3
(2 scales)		
HQ		
V/V		
(5 number groups)		
IAS		
MAG HDG		
BARO ALT		
RADAR ALT		
V/V		
(3 pointers)		
lubber		
drift		
V/V		

ADEQUACY OF NVG/HUD DISPLAY

VISUAL FATIGUE

The display was:

1	2	3	4	5
Extremely Fatiguing			Average Fatigue	No Fatigue

Reason for rating:

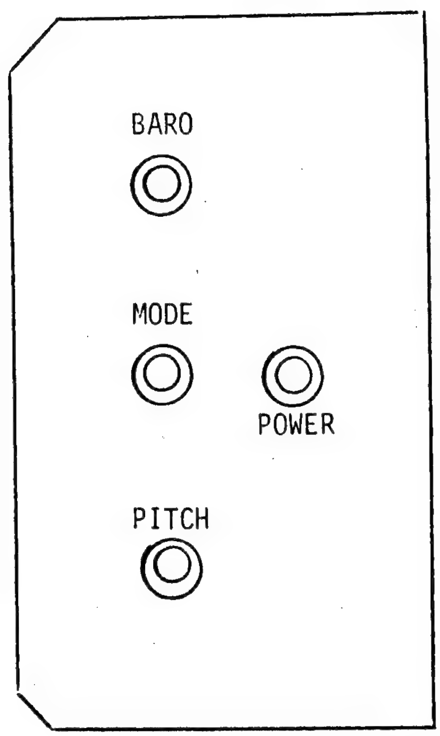
	YES	NO	COMMENTS
Focus (blur)?			
Brightness?			
Color?			
Clutter?			

MISSION USAGE

Would the NVG/HUD improve your mission performance?
(check yes or no)

YES_____	NO_____
Useful for:	The concept is wrong because of:
1.	1.
2.	2.
3.	3.

NVG/HUD PANEL



NVG/HUD COCKPIT CONTROLS

Using the diagram on the opposite page, rate each control by circling the number that corresponds to your use of this panel for night VFR operations.

The $\boxed{\textbf{MODE}}$ pushbutton is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

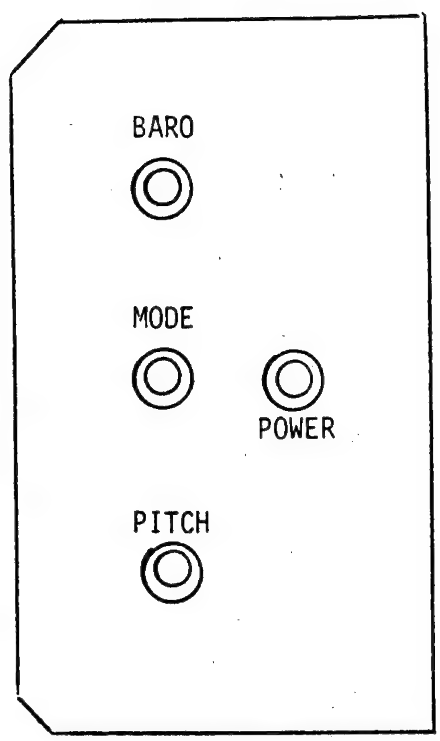
Reason for rating:

The $\boxed{\textbf{BARO}}$ pushbutton is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating:

NVG/HUD PANEL



The $\boxed{\textbf{PITCH}}$ pushbutton is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

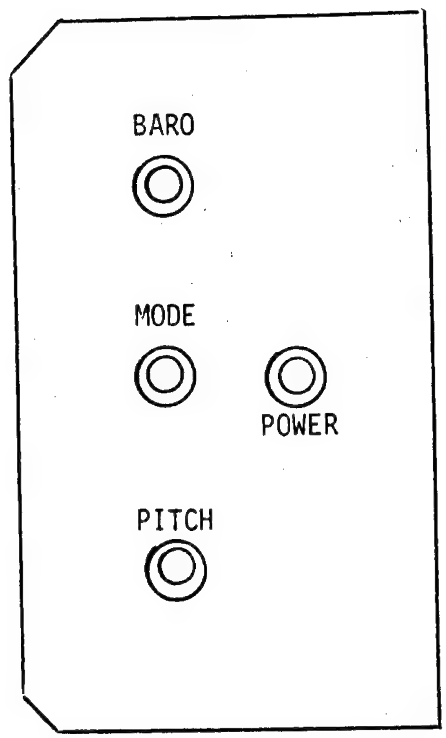
Reason for rating:

The $\boxed{\textbf{BRIGHTNESS}}$ control on the NVG is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating:

NVG/HUD PANEL



The **LOCATION** of the NVG/HUD control panel is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating (placement? Ease of use?)

The **PANEL ARRANGEMENT** of the pushbuttons and power switch is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating:

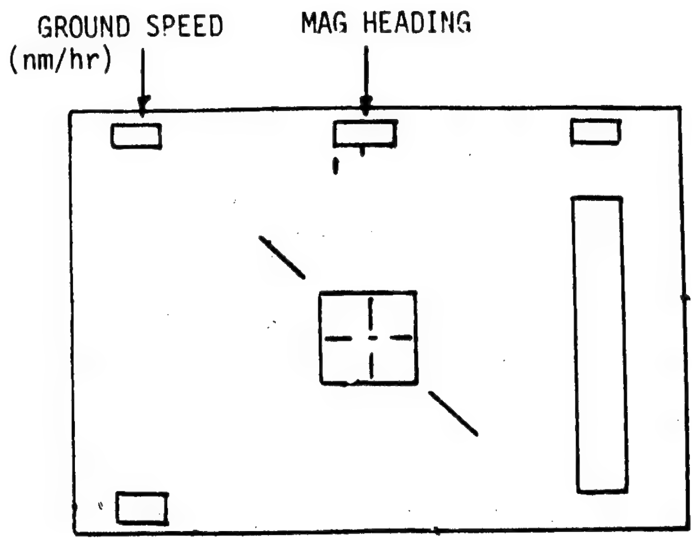
What would you change?

HH-53B/C QUESTIONNAIRE

This questionnaire will be used to gain immediate feedback about the NVG/HUD presentation used in your aircraft special operations. Please rate the adequacy of the SYMBOLS and cockpit CONTROL for a real night VFR mission.

Please follow the directions for each section of the questionnaire.

NORMAL
MODE



ADEQUACY OF SYMBOLS

Using the diagram of the NVG/HUD presentation (opposite page) as a guide, please rate each symbol by circling the number that corresponds to your impression of the presentation of the SYMBOL for flying night VFR operations and, if desired, state the reason for changing the symbol.

The **GROUND SPEED** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

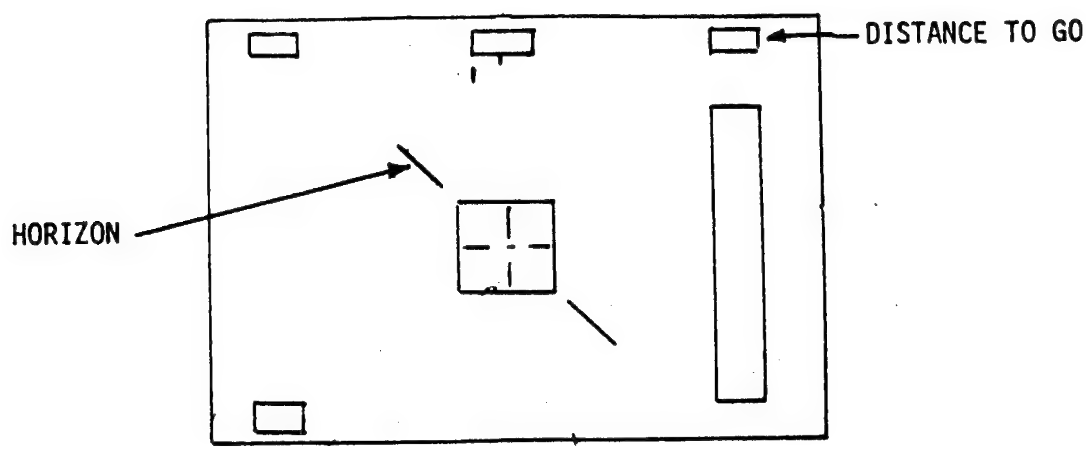
Would you change its:	YES	NO	COMMENTS
Size?			
Location?			
Width?			
Movement?			
Add a scale?			
Delete?			

The **MAG HEADING** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:	YES	NO	COMMENTS
Size?			
Location?			
Width?			
Delete?			

NORMAL
MODE



The **HORIZON** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

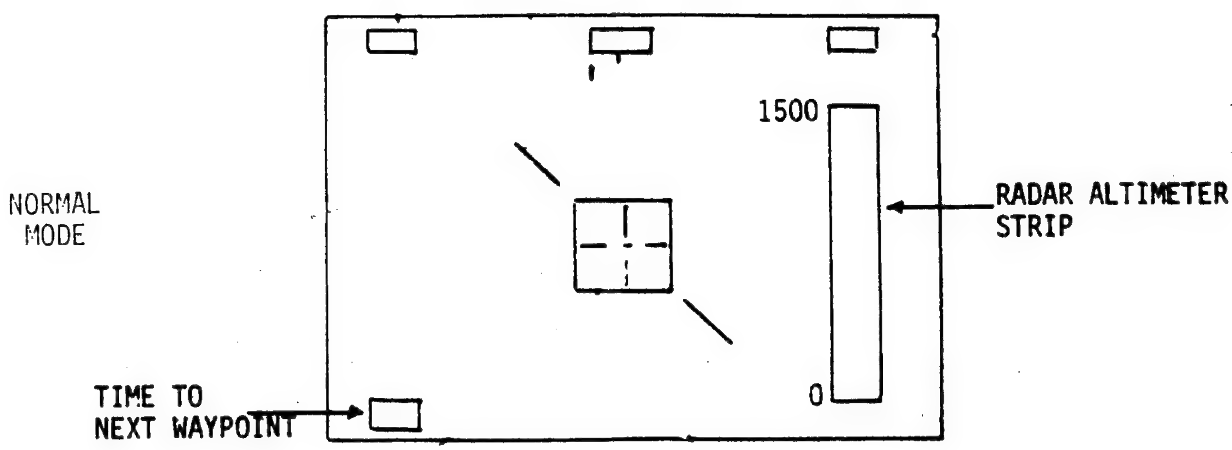
	YES	NO	COMMENTS
Size?			
Width?			
Location?			
Movement?			
Delete?			

The **DISTANCE TO GO** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Location?			
Delete?			


1500
0
RADAR ALTIMETER
STRIP
NORMAL
MODE
TIME TO
NEXT WAYPOINT

The **RADAR ALT** strip is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Location?			
Width?			
Add a scale?			
Movement?			
Add a label?			
Delete?			

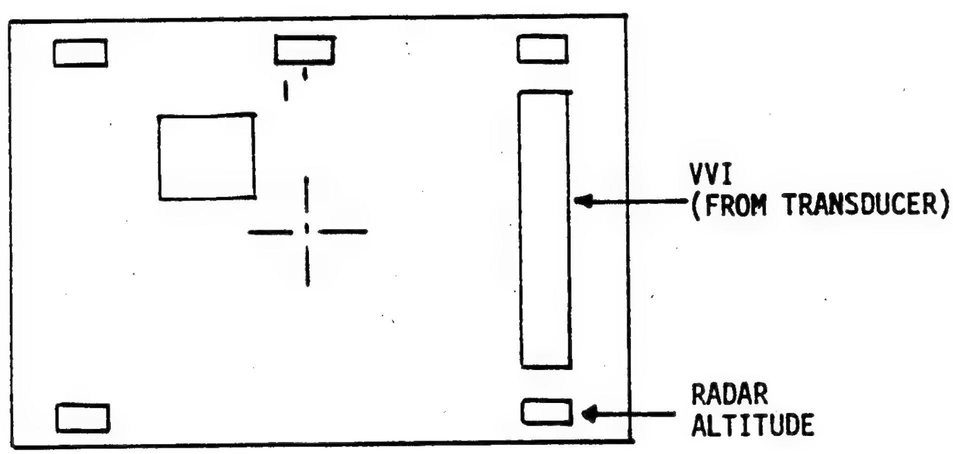
The **TIME TO NEXT WAYPOINT** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Location?			
Delete?			

HOVER
MODE



The $\boxed{\textbf{VVI}}$ symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Location?			
Delete?			

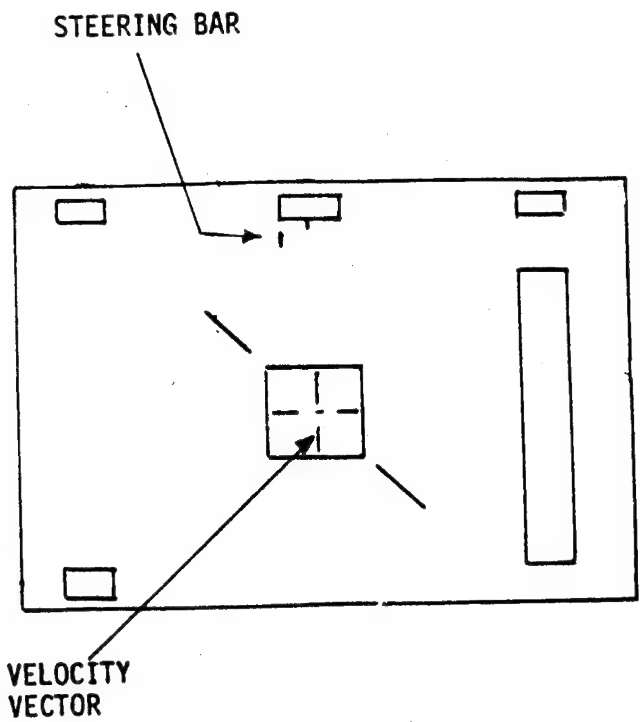
The $\boxed{\textbf{RADAR ALTITUDE}}$ symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Location?			
Delete?			

NORMAL
MODE



The **VELOCITY VECTOR** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

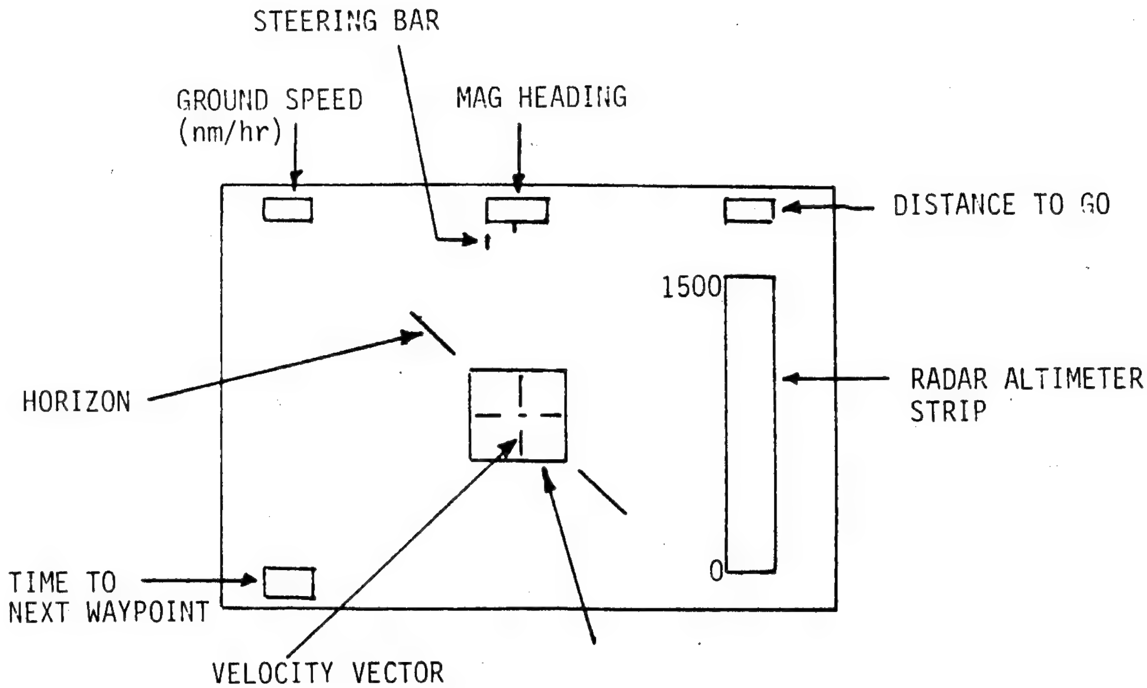
	YES	NO	COMMENTS
Size?			
Shape?			
Location?			
Box movement?			
Delete vector?			
Delete box?			

The **STEERING BAR** symbol is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Would you change its:

	YES	NO	COMMENTS
Size?			
Shape?			
Movement?			



STEERING BAR
GROUND SPEED (nm/hr)
MAG HEADING
DISTANCE TO GO
1500
0
HORIZON
RADAR ALTIMETER STRIP
TIME TO NEXT WAYPOINT
VELOCITY VECTOR

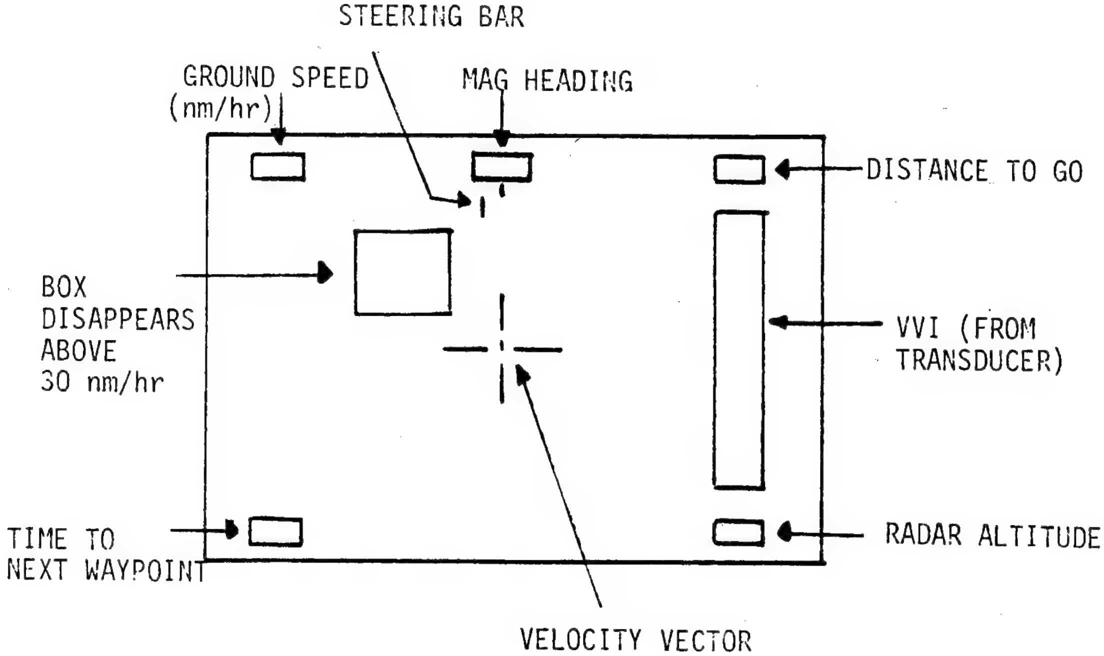
ADEQUACY OF MODES

Now that you have rated each symbol, we would like your ideas on the symbol sets for the 3 operating modes.

Using the **NORMAL** mode shown on the opposite page, please rate the need for each symbol.

1	2	3	4	5
Not Required		Moderate Requirement		Absolute Requirement

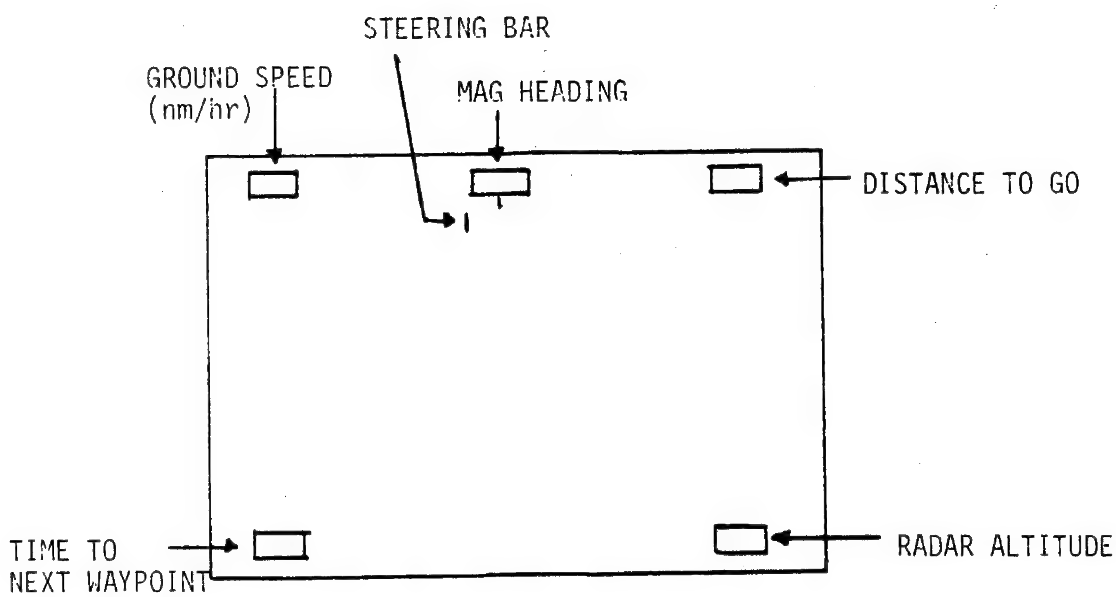
	Insert Number From Scale Above	Please Comment On Any Rating from 1 to 3
Ground speed		
Mag heading		
Steering bar		
Horizon		
Velocity vector		
Radar altimeter strip		
Time to next waypoint		
Distance to go		


STEERING BAR
GROUND SPEED
(nm/hr)
MAG HEADING
DISTANCE TO GO
BOX
DISAPPEARS
ABOVE
30 nm/hr
VVI (FROM
TRANSDUCER)
TIME TO
NEXT WAYPOINT
RADAR ALTITUDE
VELOCITY VECTOR

Using the **HOVER** mode shown on the opposite page, please indicate your requirements for each symbol.

1	2	3	4	5
Not Required		Moderate Requirement		Absolute Requirement

	Insert Number From Scale Above	Please Comment On Any Rating from 1 to 3
Ground speed		
Mag heading		
Steering bar		
Distance to go		
VVI		
Radar altitude		
Time to next waypoint		
Velocity vector		
Box		


STEERING BAR
GROUND SPEED
(nm/hr)
MAG HEADING
DISTANCE TO GO
TIME TO
NEXT WAYPOINT
RADAR ALTITUDE

Using the $\boxed{\textbf{SEARCH}}$ mode shown on the opposite page, please indicate your requirements for each symbol.

1	2	3	4	5
Not Required		Moderate Requirement		Absolute Requirement

	Insert Number From Scale Above	Please Comment On Any Rating from 1 to 3
Ground speed		
Steering bar		
Mag heading		
Distance to go		
Radar altitude		
Time to next waypoint		

ADEQUACY OF NVG/HUD DISPLAY

VISUAL FATIGUE

The display was:

1	2	3	4	5
Extremely Fatiguing		Average Fatigue		No Fatigue

Reason for rating:

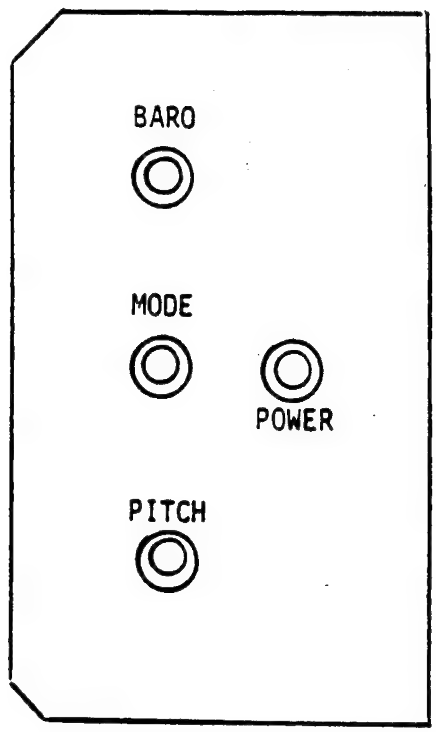
	YES	NO	COMMENTS
Focus (blur)?			
Brightness?			
Color?			
Clutter?			

MISSION USAGE

Would the HVG/HUD presentation improve your mission performance?
(check yes or no)

	YES_____ NO_____
Useful for: 1. 2. 3.	The concept is wrong because of: 1. 2. 3.

NVG/HUD PANEL



NVG/HUD PRESENTATION COCKPIT CONTROL

Using the diagram on the opposite page, rate the control by circling the number that corresponds to your use of this panel for night VFR operations.

The **MODE** pushbutton is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating:

The **BARO** pushbutton is:

1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating:

The **PITCH** pushbutton is

1	2	3	4	5
Unacceptable		Acceptable		Excellent

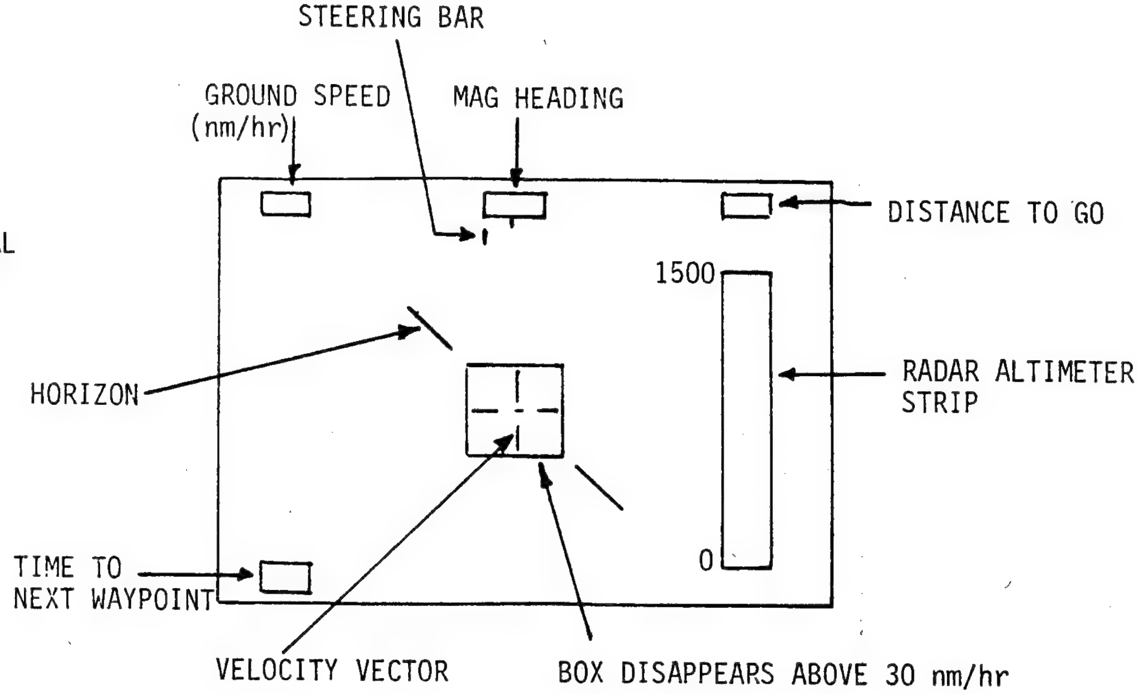
Reason for rating:

The $\boxed{\textbf{BRIGHTNESS}}$ control on the helmet is:

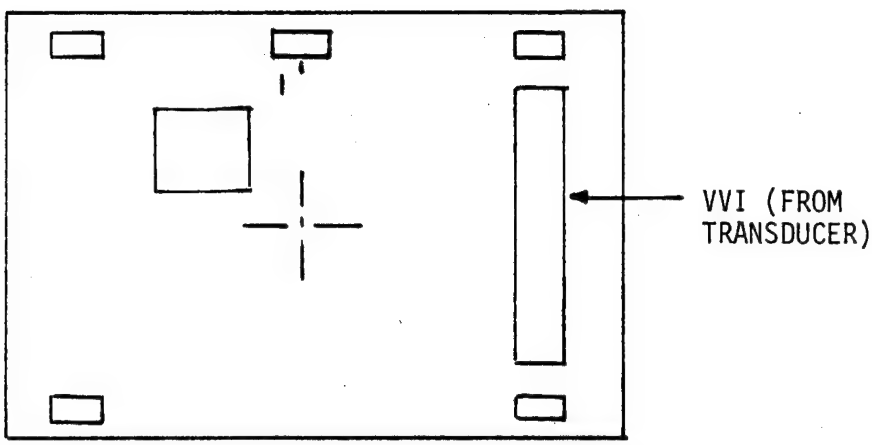
1	2	3	4	5
Unacceptable		Acceptable		Excellent

Reason for rating:

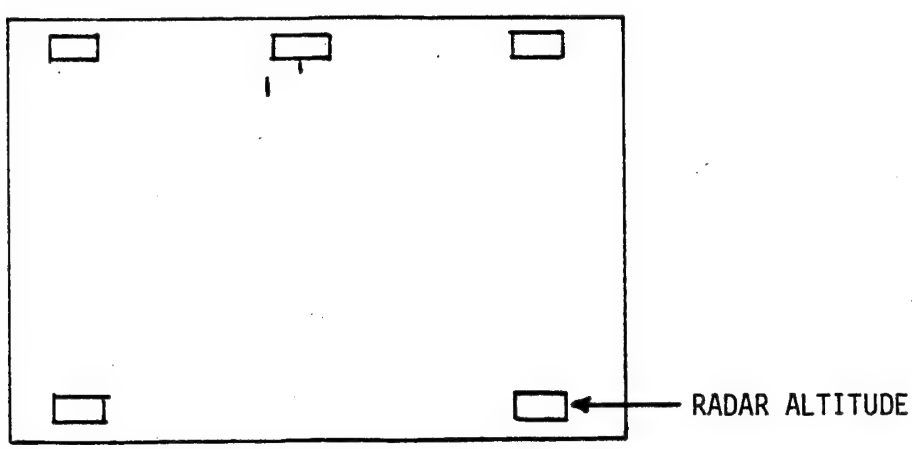
NORMAL
MODE



HOVER
MODE



SEARCH
MODE



1. What should be displayed on the NVG/HUD presentation that has not been shown?

2. If you could only have three parameters displayed, what would you require?

3. If you could only have five parameters displayed, what would you require?

Appendix C

QUESTIONNAIRE RESPONSES

This appendix includes detailed comments obtained from the pilot questionnaires which were summarized in Section 3. The comments are included for the following aircraft:

The comments were slightly edited for consistency and the number (n) of pilots who responded for each comment tallied in the right column. Not all pilots answered all questions and one pilot may have provided several comments for one question. For those questions asking for specific ratings, n = the number of pilots and the pictorial bar represents the mean rating. The higher n cases are listed first for each item.

TABLE 10. C-141B PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Pitch Ladder	Did not use.	1
Aircraft	Would delete the attitude display as visual display allows you to detect pitch and bank.	1
Horizon	Make it adjacent so you can fine tune in flight.	1
Mag Heading	Useful only during approach from 2 nm.	1
	Probably could do with one heading.	1
True Track	Could do with one type heading.	1
	Useful only enroute to approach.	1
	Make slightly larger or enclose in box.	1
Drift Angle	Did not use/not needed.	4
Radar Altitude	Needs to be at top of display during final phases of mission.	
CONTROLS		
Intensity	Difficult to locate.	1
	Needs to be on helmet.	
Location	Move to left forward cockpit.	1
DISPLAY		
HOW WOULD YOU CHANGE THE NVG/HUD DISPLAY?		
	Enlarge display.	2
	Have two displays.	1
	Cover lens with eyepieces to keep light out.	1
MISSION USAGE		
HOW COULD THE NVG/HUD CONTRIBUTE TO THE OVERALL MISSION?		
	Better control of aircraft.	3
	Increases safety.	2
	Very helpful during landing phase for airspeed and sink rate.	2

TABLE 10. C-141B PILOT COMMENTS (continued)

Items	Comments	n
	Less chatter on interphone.	1
	Less fatigue.	1
COULD THE NVG/HUD DETRACT FROM MISSION ACCOMPLISHMENT?		
	No, it could not.	4
	Could make runway acquisition difficult.	1
	Not sure.	1
SKY ILLUMINATION		
IS DISPLAY ADEQUATE FOR ALL SKY ILLUMINATION CONDITIONS?		
	Yes	4
	No	0

TABLE 11. C-130E PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Pitch Ladder		
Label steps?	10-degree increments.	1
General?	Display precessed slightly. Had to reset it from 2 degrees off to straight and level on two occasions.	2
	Had to look too long to figure out pitch; however, practice may overcome this problem.	1
Aircraft	Should be heavier lined to contrast with horizon.	1
	Original system was unacceptable; is excellent.	1
	or would better simulate the normal ADI symbol and could be easier to use.	1
Horizon Width?	Length or width should be different than aircraft symbol.	1
IAS		
Add a label?	Label it IA.	1
Delete?	Delete TAS and replace with IAS.	1
	TAS varies 100 to 300 KTAS. Range should be expanded from 30 to 300 KTAS.	1
Mag Heading		
Add a label?	Label it MH.	1
Drift Angle	Very good information.	1
	Drift was difficult to interpret with scale moving behind it. Scale could be presented ±15 degrees with hashmark for each degree. True heading is not necessary.	1
Baro Alt		
Add a label?	Label it PA.	1

TABLE 11. C-130E PILOT COMMENTS (continued)

Items	Comments	n
Vertical Vel		
Scale?	A little large, could be reduced.	1
	Numeric readout could be more readable without first digit and decimal.	1
Pointer?	Digits and pointer were both erratic and unreliable. On a 600 fpm descent, scale rapidly changed from 1700 up to 1700 down, repeatedly.	2
Digit movement?	It never worked.	1
	Erratic.	1
Radar Alt		
Add a label?	Label it RA.	1
Bank Angle	A digital readout of bank angle would save time so you would not have to count the tiny bars. Not critical, however.	1
Sky Pointer		
	I never looked at it.	2
MODE SELECTION		
Standard	True heading not needed, clutters display.	1
	Vert vel never worked.	1
	Need IAS, not TAS.	1
	Never used sky pointer; looked at bottom of display.	1
Enroute	Use IAS, not TAS.	1
	Did not use sky pointer; bottom of ADI scale is most important.	1
	Do away with this mode. Standard mode should be used during all phases. Gets pilot used to seeing same information.	1
Landing	Vertical vel would be nice to have.	1
	Mag heading not useful; you should be be visual on runway. Only useful for initial alignment.	1
	Lubber line not needed.	1
	Delete this mode.	1
	Prefer to use standard mode during approach and landing.	1

TABLE 11. C-130E PILOT COMMENTS (continued)

Items	Comments	n
CONTROLS		
The **MODE** pushbutton is:		
	Unacceptable 1 — 2 — Acceptable 3 — 4 — Excellent 5	
		5
	Easy to operate.	1
	Will not be needed if HUD is only used in standard mode.	1
	Should be the top switch since it is most used.	1
The **BARO** pushbutton is:		
	Unacceptable 1 — 2 — Acceptable 3 — 4 — Excellent 5	
		5
	Easy to set.	1
	Easy to find and operate in dark.	1
The **PITCH** pushbutton is:		
	Unacceptable 1 — 2 — Acceptable 3 — 4 — Excellent 5	
		5
	Simple to operate.	1
	Easy to set.	1
BRIGHTNESS		
The **BRIGHTNESS** control in the NVG is:		
	Unacceptable 1 — 2 — Acceptable 3 — 4 — Excellent 5	
		4
	Did not use.	1
	You pick your own brightness.	1

Items	Comments	
LOCATION		
The **LOCATION** of the NVG/HUD panel is:		
	Unacceptable 1 — 2 — Acceptable 3 — 4 — Excellent 5	
	[bar extending to 5]	5
	Easy to find.	1
	It is within easy reach of the pilot.	1
	No problems.	1
PANEL ARRANGEMENT		
The **PANEL ARRANGEMENT** of the pushbuttons and power switch is:		
	Unacceptable 1 — 2 — Acceptable 3 — 4 — Excellent 5	
	[bar extending to 5]	5
	Once you learn where each button is, it is fine.	1
	I would like mode button on top.	1
	Would not change it.	1
	If mode switch is disengaged, arrangement is better providing separation between baro and pitch controls.	1
	I think possibly a ride in the simulator with the pilot doing the enroute flying would really help the pilot adapt to displays faster. I had to ignore some of the information.	1

TABLE 11. C-130E PILOT COMMENTS (continued)

Items			Comments	n
VISUAL FATIGUE				
The display was:				
Extremely Fatiguing 1	2	Average Fatigue 3	4 No Fatigue 5	
				5
	Yes	No		
Focus (Blur)?	3	1	Hard to focus was biggest fatigue problem.	1
			A lot of difficulty of focusing.	1
			Constant refocusing causes minor fatigue.	1
Brightness?	2	3	I think this was due to full moon.	1
			In order to see HUD after landing, lights were turned on. I had to keep it brighter than necessary during other phases of flight.	1
Color?		4		
Clutter?	2	2	You need to hang the wires in such a way that they do not get tangled up in the pilot's head rest. This happened several times during the flight.	1
			Display was (overall) too small. Needs to be doubled in size.	1
			Due to the weight of the helmet and the NVGs, it was fatiguing trying to keep them on your head.	1
			Most left seaters constantly cross-checked copilot. Reticle would be more convenient on left tube.	1
			It was somewhat distracting to use a mode other than the landing mode for landing.	1

TABLE 11. C-130E PILOT COMMENTS (continued)

Items	Comments	n
MISSION USAGE		
Would the NVG/HUD improve your mission performance?		
Yes: 3, No: 1	Useful for:	
	Night landings.	1
	Night navigation.	1
	Low level low light conditions.	1
	NVG approaches.	1
	NVG air drops.	1
	Enroute navigation under reduced moonlight.	1
	Allowing pilot to fly aircraft during enroute with NVGs on makes flight at 800 feet more realistic while complying with Chapter 27.	1
	Allows pilot to fly approach and landing, freeing copilot to map read and act as safety.	1
	The concept is wrong because:	
	NVGs are not used for the route, and it takes away from flying and chart reading and causes an extra pair of eyes to be in the cockpit and not outside.	1
	Even for the approach, I prefer the NAV and copilot to be crosschecking air-speed, altitude, and not just dependent on the pilot, and I found myself depending on them more than the HUD.	1
	Other comments:	
	Four approaches are not enough to make that conclusion, since it requires a whole new revision in procedures. To the extent that I used it, it did degrade my landings somewhat. Not so much due to the HUD, but to my inability to get a really clean outside picture.	1

TABLE 11. C-130E PILOT COMMENTS (continued)

Items	Comments	n
	Rely on old methods in order to fly safely because of my being unfamiliar with the system.	1
	VVI was erratic and unusable.	1
	Overall HUD presentation was half the size it needed to be.	1

TABLE 12. MC-130E PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Ground Speed		
Location	All symbols need to be moved to the edge of the pilot's field of vision.	1
	Move to other edge of picture.	1
	Unnecessary.	1
Aircraft	Unnecessary.	1
	Too large, busy, and cluttered.	1
Horizon		
Width	Good.	1
Rate of Movement	Too much.	1
TAS		
Size	Larger.	4
Location	Move toward the outside perimeter of the display.	3
Mag Heading		
Size	A little larger.	1
Delete the Scale or Lubber Line	Change to course (INS).	1
Drift		
Delete	Unnecessary.	1
Baro Alt		
Location	Drop to bottom of case.	1
Movement	Smaller increments, change to 10 or 20.	1
Delete	Unnecessary, need radar altimeter only.	1
	Not useful or limited use.	1
Vert Vel		
Scale	Move to the edge.	1
Pointer	Only two digits have ▲ for climb, add ▶ for dive.	1
	Not necessary, only need digital and climb/dive indication.	1
	Little larger.	1
	Don't need it.	1
Location	Further to right edge of scope.	1
Movement of Digits	Don't need digits.	1

TABLE 12. MC-130E PILOT COMMENTS (continued)

Items	Comments	n
Movement of Pointer Scale	Make pointer larger.	1
Delete Decimal	No digits/no 0 or decimals.	1
Radar Alt		
Size	Switch with baro altimeter.	1
Movement	Change increments to 25 or 50 feet above 1000 and 5 to 10 below 1000.	1
	Below 100 feet it moved far too rapidly.	1
Bank Angle		
Shape	Too many, use the same scale as our normal ADI (i.e., 10°, 20°, 30°, 60°, 90°).	1
	Too tight.	1
Size	Wider in FOV.	1
	Too small.	1
Scale	10° increments to 30°.	1
	Too much.	1
	Unnecessary, clutters up picture.	1
Standard Mode		
Vert Vel Pointer	Digital readout only helps clear up display, gives information necessary.	1
	Have pointers for up or down.	1
	I don't feel a need for an ADI for our mission. The pilot only lands on NVGs. We have ATF radar for enroute flying.	1
Radar Alt	Good for low level and landing phases of flight; not applicable for ground or takeoff.	1
Baro Alt	Only required when you know elevation over which you are flying.	1
	I don't feel the need for baro alt. The radar alt is all that is required.	1
Vert Vel Scale	Change to 2 digits.	1
Lubber	Tells me nothing by itself.	1
Drift	Drift is not that important that it requires so much space.	1
Sky Pointer	Only slightly useful in our aircraft.	1
Lubber-Sky	Clutters view, unnecessary.	1
	Only slightly useful in our aircraft.	1

TABLE 12. MC-130E PILOT COMMENTS (continued)

Items	Comments	n
Enroute	We don't need an enroute mode.	1
	All information is useless.	1
Heading	Digital readout would suffice.	1
IAS	Good for crosscheck.	1
Baro Alt	Need AGL more than MSL.	1
	Only good if you know elevation under you.	1
Lubber	Tells me nothing in itself. Not too important enroute, I can ask my navigator.	1
Drift	Can be used as a crosscheck.	1
Sky Pointer	Not necessary in our aircraft.	1
	Need to include bank pitch bars if we are to incorporate HUD into our tactics.	1
Landing		
HQ	Digital readouts should suffice.	1
Vert Vel	Have pointers.	1
Pointer	Not required.	1
IAS	Good.	1
Mag Heading	No required, CRS is.	1
	Moderately useful for crosscheck.	1
Baro Alt	Not required.	1
	Only good with alt cal.	1
Radar Alt	Good but bad readout.	1
Vert Vel Scale	Good but bad readout.	1
Lubber	Useful for crosscheck.	1
	Not useful.	1
	Remove.	1
Drift	Okay.	1
	I never look at drift indicator, only outside picture for drift.	1
Vert Vel	Delete.	1
	GS would aid. Useful for TOT/TOA control to seconds accuracy.	1

TABLE 12. MC-130E PILOT COMMENTS (continued)

Items	Comments	n
CONTROLS		
Mode Pushbutton	Needs to be located on yoke if it is to be useful.	2
	Did not use this panel. Flew five approaches as NVG safety and only one in left seat.	1
	Bad location, can't change it if flying.	1
Baro Pushbutton	Did not use.	1
	Do not need a pressure altitude near as much as an absolute (radar) altitude.	1
	Difficult to reach. Two-way toggle would be helpful rather than double push for wrong way. Small adjustments were difficult.	1
	Baro alt not really important.	1
Pitch Pushbutton	Can't fly and change.	1
	Needs toggle. Too many pushes required. If your first correction is not perfect, two pushes are required to reset again. Cumbersome.	1
	Did not need at all.	1
	Did not use.	1
	Location on Fulton yolk panel is perfect.	1
Brightness Control	In bad location, should be someplace else than on right temple.	1
	Time consuming. Didn't work.	1
	Did not use.	1
	Did not notice.	1
	Should be on the panel, not on helmet.	1
	Adjustments are good.	1
	It was hard to get at if you were flying.	1
Location of Control Panel	Place nearer to yoke.	1
	Can't change and fly.	1
	It was fine. I had no trouble locating it.	1
Panel Arrangement	Too busy in area of pitch control, remove control.	1
	It was fine. All you have to do is remember which is which.	1

TABLE 12. MC-130E PILOT COMMENTS (continued)

Item	Yes	No	Comments	n
VISUAL FATIGUE				
			Extremely Fatiguing 1 — 2 — Average Fatigue 3 — 4 — No Fatigue 5	6
Focus (Blur)?	3	1	Standard mode was too busy. Display needs to be expanded. Use more of the tube that is available. Part of the visual fatigue was refocusing of the eye. Focus was too close in. Have to refocus into symbology then out for running.	3
Brightness?	3	2	Brightness is okay at low intensity, but we didn't find this feature until late in the mission. Brightness is unacceptable at high intensities.	
Color?	0	3	Color was fine.	
Clutter?	6	0	Too cluttered for MC ops; needs to be reduced in quantity and expanded to edge of field of view. Having the display right in the center really caused a great deal of fatigue.	3

TABLE 12. MC-130E PILOT COMMENTS (continued)

Items		Comments	n
MISSION USAGE			
Would the NVG/HUD improve your mission performance?			
Yes	No		
3		Useful for:	
		It's nice to have, but not necessary for us.	1
		NVG approaches and landings.	1
		Possibly for safety.	1
		Approaches (to monitor more accurately).	1
		Enroute (as backup).	1
	1	The concept is wrong because:	
		Landing pilot has to refocus.	1
		No ILS, no glide slope, poor digitized data.	1
		Oral aids provided by navigators were more useful than the numbers.	1
		Experiment with a pilot who has never used any type of NVG.	1

TABLE 13. HC-130P PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Horizon		
Width	Make slightly wider to differentiate.	1
	Make it more distinguishable; thicker.	1
IAS		
Movement	Digits change too fast.	1
Drift		
Size	Slightly larger.	1
Baro Alt		
Movement	Movement during climb/descent much too fast (for how small the figures are) to get any kind of good indication. Suggest to reduce scale - put in increments of 100' (50' at the most).	1
	Didn't work.	1
Vert Vel Pointer	Pointer and scale are ideal, but the movement of digits is too fast to make out actual rates. However, with the scale and pointer the VVI is still very usable.	1
Radar Alt	Although this function was inop to unreliable, the rate of scale movement seemed to be slower.	1
Bank Angle		
Shape	Would like to see more of a point than a dash ▼ . Also it would be nicer if it was larger.	1
Size	Too small, very hard to read.	1
Sky Pointer		
Shape	Didn't use it.	1
	Make it a point ▲ .	1
Pitch Ladder		
Label Steps	Climb and dive indicators.	1
Add Above/ Below Horizon Cues	Could add this.	1

TABLE 13. HC-130P PILOT COMMENTS (continued)

Items	Comments	n
Standard Mode	As for rating the standard mode, I thought all symbols and separate systems complement each other well.	1
Heading and Lubber	Recommend a stationary heading scale to show drift.	1
Sky Pointer	Not really used.	1
Enroute Mode	As far as SOLL flying, I cannot see any reason for using the enroute mode. The radar alt is a must as is the VVI indication. With the lead aircraft, you would use the standard mode. For #2 in a formation, you would use the landing mode.	1
	Really only needed in weather. It would be nice if altitude information could be deleted in VMC.	1
	Would like to add radar alt for low level.	1
Heading	Recommend stationary scale.	1
Landing Mode	This is great while flying #2 aircraft in formation. It takes the ADI type indicators out which you don't need, but allows you to crosscheck while maintaining position.	1
CONTROLS		
HQ	Should be stationary to provide drift angle.	1
Mode Pushbutton	Did not use.	1
Baro Pushbutton	Didn't work.	1
	Didn't use.	1
Pitch Pushbutton	Didn't use.	1
Brightness Control	Need dual brightness controls; controls at each HUD display.	1
	Need to be able to adjust each display separately.	1
Panel Arrangement	Did not use.	1

TABLE 13. HC-130P PILOT COMMENTS (continued)

Items	Comments					n
VISUAL FATIGUE	Extremely Fatiguing 1	2	Average Fatigue 3	4	No Fatigue 5	
						2

Items	Yes	No	Comments	n
Focus (Blur)?	1		Bottom half slightly out of focus.	1
Brightness?	1	1	Spread out display into the edges of field of view.	1
Color?		2	Very clear - almost better than the goggles.	1
Clutter?	1	1	Need to have separate brightness controls for each position.	1

MISSION USAGE		
Would the NVG/HUD improve your mission performance?		
2	Useful for:	
	Makes for increased safety.	1
	Allows accomplishment of SOLL.	1
	Excellent for all aspects of SOLL, low level formation and refueling.	1
	Allows crosscheck of copilot/pilot and lead aircraft.	1

TABLE 14. HH-53H PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Ground Speed		
Size	Increase size slightly (X 1.5).	4
	Needs focus.	
	Move outboard in display.	
True Heading		
Size	Increase size (X 1.5).	4
	Focus.	
TF Command Box		
Size	If it was larger you would be able to detect smaller movements better.	1
Time		
Size	Make larger.	3
Shape	Needs to have real-time displayed instead of operating time.	1
Location	Center bottom of display.	1
Delete	What good is it.	1
Waypoint Steering Point		
Size	Make bigger.	1
Location	Move up a little.	1
Width	Make wider (X 1.5).	1
Distance to Go		
Size	Increase size.	3
	Focus.	1
	It is very hard to read because of its size and location. The last number is indistinguishable because its too far to the right.	1
Radar Alt		
Size	Make larger.	1
Delete	Add numeric numbers (i.e., 300, 200, etc. in lower right hand corner).	1
Normal Mode		
Ground Speed	Too small.	1
True Heading	Too small.	1
Horizon	Too small.	1
Radar Altitude	Too small.	1
	Delete strip, add numeric values.	1
	Too small.	1

TABLE 14. HH-53H PILOT COMMENTS (continued)

Items	Comments	n
Waypoint Steering Bar	Too small.	1
Distance to Go	Too small.	1
Time	This was not on the prototype used for test.	1
	Too small.	1
Aircraft	Too small.	1
TF Box	Too small.	1
Hover Mode		
Ground Speed	Too small.	1
True Heading	Too small.	1
Distance to Go	Too small.	1
Radar Altitude	Too small.	1
VVI	Eliminate the # on the side of the arrow.	1
	Digital VVI readout not required; only the arrow and line scale.	1
	Too small.	1
SEARCH MODE		
Ground Speed	Too small.	1
True Heading	Too small.	1
Distance to Go	Too small.	1
Time	Too small.	1
Radar Altitude	Would rather have a tape.	1
	Need steering bar.	1
What should be displayed on the NVG/HUD presentation that has not been shown?		
	Need steering bar on the search mode.	1
	Put a steering bar on the search mode.	1
	Possibly VVI.	1
	Nothing.	1
If you could only have three parameters displayed, what would you require?		
	Ground speed.	3
	True heading.	3
	Steering.	3
	Distance to go.	2
	Radar altitude.	1
	Altitude.	1
	TF command.	1
	Horizon.	1

TABLE 14. HH-53-H PILOT COMMENTS (continued)

Items	Comments	n
If you could only have five parameters displayed, what would you require?		
	True heading.	2
	Steering.	2
	Radar altitude.	2
	Items on search mode.	2
	Time.	2
	Climb CMD/with horizon.	1
	TF command.	1
	Horizon.	1
	Distance to go.	1

VISUAL FATIGUE

Extremely Fatiguing 1	2	Average Fatigue 3	4	No Fatigue 5	n
					4

Items	Yes	No	Comments	n
Focus (Blur)?	1	1	Had to focus in constantly to read information.	3
Brightness?	1		Brightness could not be adjusted.	1
Color?		1	Need to diffuse background light around HUD.	1
Clutter?	1		Spread symbols throughout the viewing area.	1
			Symbology is located too close to center of view. Need to move numbers out to edge of circle.	1

TABLE 14. HH-53H PILOT COMMENTS (continued)

Items			Comments	n
MISSION USAGE				
Would the NVG/HUD presentation improve your mission performance?				
	5	0	Useful for:	
			It would eliminate need for FC to tell pilot critical information.	1
			Useful for everything if it was made larger and focused at infinity. Needs individual intensity controls.	1
			Approaches into LZ.	1
			Enroute information up front.	1
			Target ingress.	1
			Inadvertant WX penetration.	1
			Low level navigation.	1
			NVG profiles.	1
			Back up to degraded FLIR.	1

TABLE 15. HH-53B/C PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Ground Speed		
Size	Too small.	1
Location	Movement of entire display should be on a rheostat to move entire display anywhere within confines of tube.	1
Mag Heading		
Size	Too small.	1
Distance to Go		
Size	Not applicable.	1
Radar Alt		
Location	See ground speed.	1
Add a Scale	25 foot increments.	1
Time To Next Waypoint	Didn't work.	1
VVI		
Delete	Not needed.	1
Radar Alt		
Size	Too small.	1
Velocity Vector	Didn't work.	1
Steering Bar	Didn't work.	1
Normal Mode		
Steering Bar	Needs relativity scale.	1
Velocity Vector	Need relativity scale.	1
Hover Mode		
VVI	Don't need.	1
Time to Next	Don't need.	1
Waypoint	Serves no purpose in hover.	1

TABLE 15. HH-53B/C PILOT COMMENTS (continued)

Items	Comments	n
VISUAL FATIGUE		
Clutter	Sometimes it was in the way. It would be nice to be able to move complete display around, as required, inside tube diameter.	1
MISSION USAGE		
Useful For:	Staying oriented.	1
	Staying alive.	1
	Everything we do.	1
If you could only have three parameters displayed, what would you require?		
	Mag heading.	2
	Horizon.	1
	Steering bar.	1
	Ground speed.	1
	Altitude.	1
If you could only have five parameters displayed, what would you require?		
	Mag heading.	2
	Radar altitude.	2
	Horizon.	1
	Steering bar.	1
	Ground speed.	1
	Calibrate steering.	1
CONTROLS		
Mode Pushbutton	Put it on the cyclic.	1
Pitch Pushbutton	Change button to the center sprung type up for up, down for down.	1
Brightness Control	I don't like it, but I can't think of anything better.	1

TABLE 16. UH-60A PILOT COMMENTS

Items	Comments	n
SYMBOLS		
Ground Speed		
Size	Make larger.	2
Location	Farther to the outside of the tube.	1
Heading Speed		
Size	Larger.	1
Location	Farther to the outside of the tube.	1
Time		
Size	Larger.	2
Location	Put it with distance to waypoint.	2
	Farther out.	1
Waypoint Steering Point		
Size	Larger.	1
	Put it on the search NVG/HUD. Presentation mode.	1
Distance to Go		
Size	Make bigger.	2
Location	Put with time to go display.	1
	Put farther out.	1
Radar Alt		
Location	Put farther out.	1
Add a Scale	Need smaller scale for hover and approach modes. Suggest increments of 5 feet up to 100 feet and 25 feet up to 200 feet.	
	For helo operations, change the scale from 0 to 3000 feet to maybe 0 to 500 feet.	
Normal Mode		
Ground Speed	Suggest indicated airspeed instead.	1
Horizon	Only for inadvertant IMC possibility.	1
Radar Altimeter	Suggest large 100-foot increments and small 5-foot and 25-foot scales.	1
Time	Could be better if it were actual time in Zulu.	1
Aircraft	Needed for hover mode.	1
TF Box	Needed for hover mode.	1

TABLE 16. UH-60A PILOT COMMENTS (continued)

Items	Comments	n
Hover Mode		
Ground Speed	Not required.	1
Distance to Go	Not required.	1
Radar Altitude	Need small scale radar altitude (imperative).	1
VVI	Did not use much.	1
	Not responsive enough to be of value.	
Time	Not much use.	
Search Mode		
Ground Speed	Need indicated airspeed readout.	1
Time	Could be time to next waypoint.	
What should be displayed on the NVG/HUD presentation that has not been shown?		
	A low altitude light that comes on when below low setting on radar altimeter.	1
	A trim bar on display.	1
If you could only have three parameters displayed, what would you require?		
	Heading	2
	Altitude.	1
	Distance to go.	1
	Steering bar.	1
	Ground speed.	
If you could only have five parameters displayed, what would you require?		
	Heading.	2
	Distance to go.	2
	Steering bar.	2
	Ground speed.	1
	Altitude.	1
	Time to go to next waypoint.	1

TABLE 16. UH-60A PILOT COMMENTS (continued)

Items	Comments	n
VISUAL FATIGUE		
The display was:		
Extremely Fatiguing 1 — 2 — Average Fatigue 3 — 4 — No Fatigue 5		
(bar spanning 1 to 3)		2
Yes / No		
Focus (Blur)? 1 / 1		
Brightness? 1 / 1		
Color? — / 2		
Clutter? 1 / 1	Seems to be too much clutter in the middle of tube.	1
MISSION USAGE		
Would the NVG/HUD presentation improve your mission performance?		
2		2
	Useful for:	
	Heading information.	1
	Altitude information.	1
	Hover mode.	1
	Time to go.	1
	Distance to go.	1
	Navigation.	1
	Situation awareness.	1

TABLE 16. UH-60A PILOT COMMENTS (continued)

Items	Comments					n
CONTROLS						
	Unacceptable 1	2	Acceptable 3	4	Excellent 5	
NORMAL MODE						2
HOVER						2
SEARCH						2
NORMAL HOVER AND SEARCH MODE						
REASON FOR RATING:	Should be incorporated into cyclic.					1
	They were all simple to use.					1

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